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Symposium on Middle and Upper Devonian Stratigraphy of Pennsylvania and Adjacent States

Editor

VINCENT C. SHEPPS

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Symposium on Middle and Upper Devonian Stratigraphy of Pennsylvania and Adjacent States

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Symposium on Middle and Upper Devonian Stratigraphy of Pennsylvania and Adjacent States

Vincent C. Shepps
Editor

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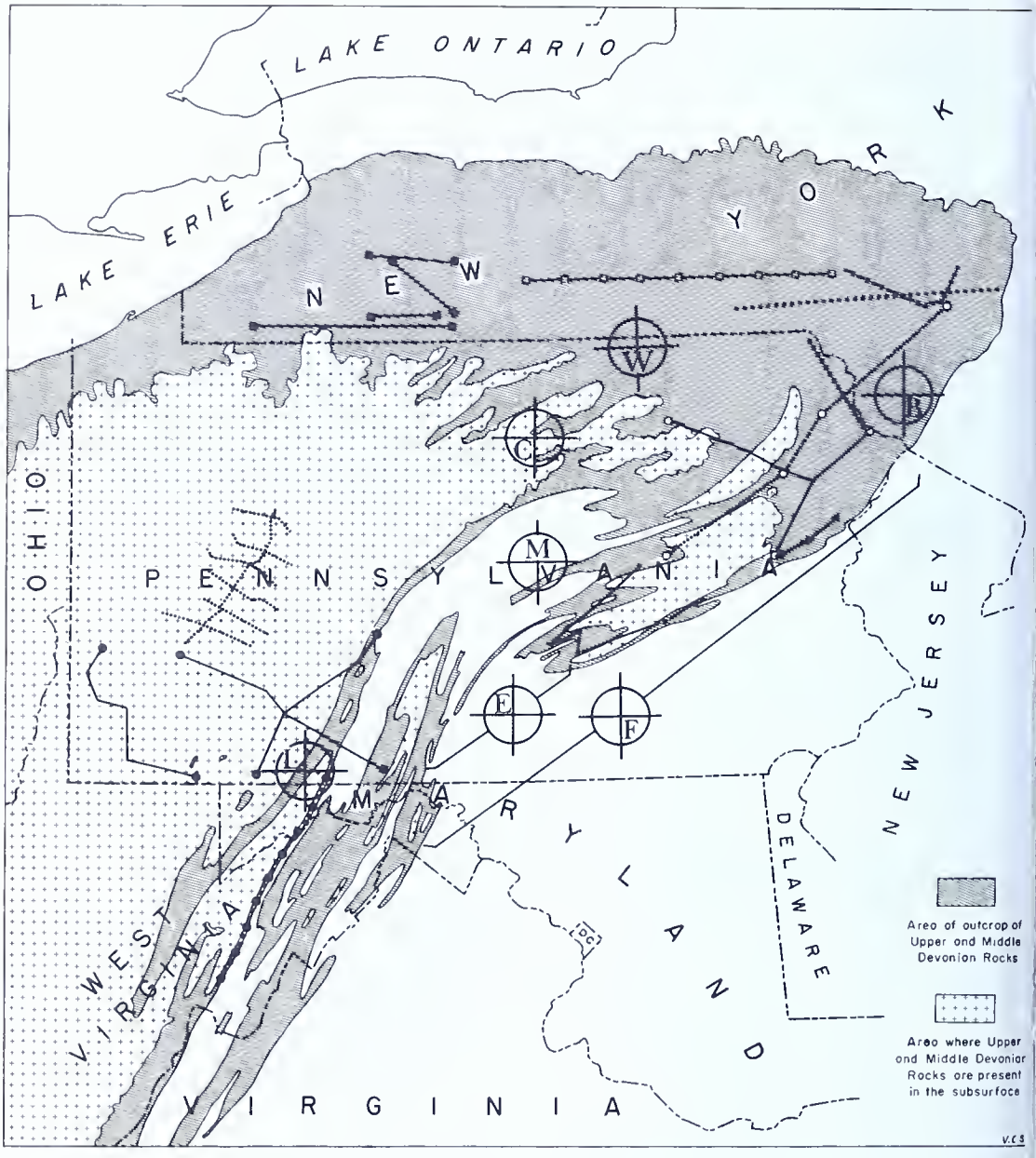

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LOCATION OF SUBREGIONAL OR LOCAL STUDY CONTAINING CORRELATION DIAGRAMS

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	Cate
C	Colton
	Dennison
E	Ellison
	Fletcher
F	Frakes
	Glaeser
	Hoskins et al
L	Leeper
	Manspeizer
M	Meyer
	Sutton
	Wagner
	Wietrzychowski
	Wolfe
W	Woodrow

REGIONAL STUDIES: Ayrton; Wheeler; Woodward

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Symposium on Middle and Upper Devonian Stratigraphy of Pennsylvania and Adjacent States

INTRODUCTION

Catskill rocks and their adjacent strata have become a classic stratigraphic model during the past century. Recognition of the complex characteristics of the section, including vertical repetition and lateral variations in lithology and fauna, has been at the forefront of significant developments in stratigraphy.

An examination of the history of geologic research on Middle and Upper Devonian strata in the Appalachians reveals that important contributions cluster in short periods between long intervals of relative inactivity. The initial work of state geologic surveys in the 1830's to 1850's is certainly one of the significant periods, as is the time around the turn of this century. Another stage of intensive study took place in the 1930's when major ideas derived from studies of specific stratigraphic units were synthesized into a regional concept. Major advances in the field of Middle and Upper Devonian stratigraphy in eastern United States are attributed to such workers as James Hall, I. C. White, Joseph Barrell, Bradford Willard, Kenneth E. Caster, and George H. Chadwick.

The most recent surge in research on the Middle and Upper Devonian section had its initiation in the late 1950's. This was spurred by work done in the preparation of new state geologic maps, and is continuing at present. Results of detailed field mapping and subsurface exploration, coupled with the recognition that litho-, bio-, and chrono-stratigraphic units each may be useful in establishing stratigraphic frameworks, stimulated an intensified examination and reevaluation of established concepts. As a result, enormous amounts of information have been gathered, much of which has yet to be understood from a regional viewpoint.

This symposium volume assembles a large quantity of new information. The volume is characterized by diversity of data, approach, nomenclature, and interpretation of a single succession of strata. It is hoped that by bringing together a large amount of information pertaining to this portion of the stratigraphic column that further work and thought will be stimulated.

To permit a maximum of freedom of communication, no restrictions have been imposed upon contributors in terms of editorial policy or nomenclature, although authors were requested to follow the Code of Stratigraphic Nomenclature (American Commission on Stratigraphic Nomenclature, 1961). The publication of new or existing nomenclature in this volume does not necessarily mean that this nomenclature is accepted by the Pennsylvania Geological Survey.

The cochairmen wish to express their sincere appreciation to the authors of the articles contained herein for their participation in this symposium and cooperation in meeting publication deadlines. Through the efforts of V. C. Shepps, Editor, Pennsylvania Topographic and Geologic Survey, it has been possible to present this volume in a matter of weeks after submission of manuscripts. His direction of all phases of technical organization of this volume is gratefully acknowledged.

Cochairmen,

Lawrence A. Frakes
J. Douglas Glaeser

WILLIAM G. AYRTON, *Dept. Geology, Northwestern Univ., Evanston, Illinois*

Isopach and Lithofacies Map of the Upper Devonian of Northeastern United States[1]

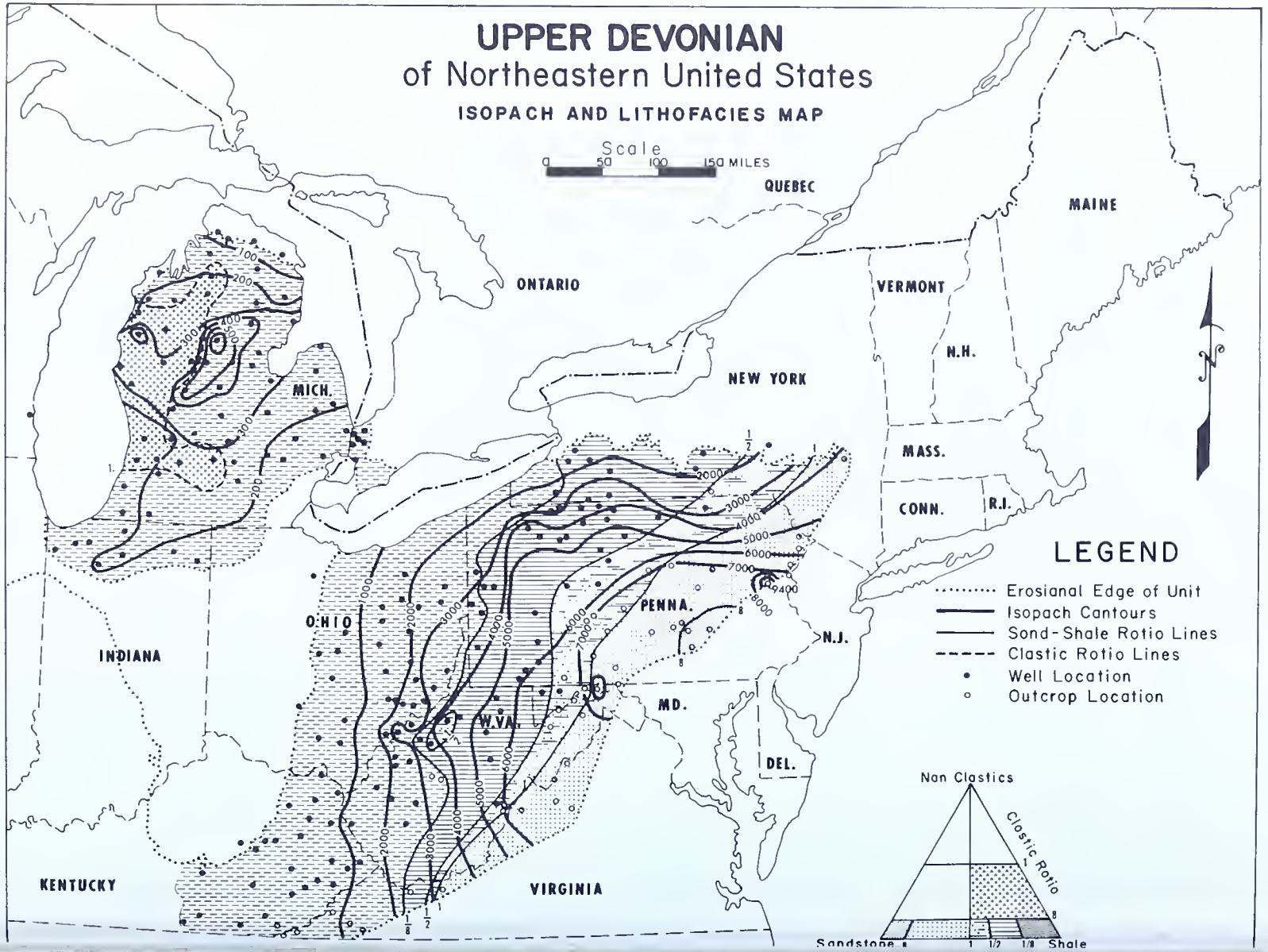
INTRODUCTION

This map has been prepared from stratigraphic data available in the literature and from unpublished well-logs provided by the Pennsylvania Geologic Survey. In this study, Upper Devonian strata are operationally defined as those rocks which underlie the Pocono and Berea Formations and which overlie the Onondaga Limestone, or in the absence of that unit, the Tully Limestone. When both the Onondaga and the Tully Limestone are unrecognizable, the lower limit of the operational unit is taken as the Genesee Shale. The unit does not embrace a major uncomformity, and the basic assumption is made that at any point within the area under investigation, the thickness of the unit is representative of the total depositional thickness at the point (except at the erosional edge of the unit). The stratigraphic data were processed by an IBM 650 Computer following a program described by Krumbein and Sloss (1958) and the map was constructed following the method outlined by Sloss, Dapples and Krumbein (1960).

ISOPACH PATTERN

The operationally defined Upper Devonian unit presents an excellent example of shifting facies, and the changes in both thickness and lithology are typically those of a clastic wedge. The isopach pattern indicates the presence of two basins and one major positive source which were active during the Late Devonian; namely the Appalachian and Michigan Basins and the Acadian Mountains. The isopach pattern also illustrates the enormous thickening of sediments in the east, and a gradual westward thinning of the wedge toward the Cincinnati Arch. The unit can be traced

[1]Synthesis of report submitted for seminar on regional stratigraphic analysis on file in Department of Geology, Northwestern University. Map based entirely on published information. Published with permission of Dr. L. L. Sloss.


UPPER DEVONIAN
of Northeastern United States
ISOPACH AND LITHOFACIES MAP
Scale
0 50 100 150 MILES
QUEBEC
ONTARIO
MAINE
VERMONT
N.H.
NEW YORK
MASS.
CONN.
R.I.
MICH.
OHIO
INDIANA
PENNA.
N.J.
MD.
DEL.
W.VA.
KENTUCKY
VIRGINIA
LEGEND
Erosianal Edge of Unit
Isopach Cantours
Sond-Shale Rotio Lines
Clastic Rotio Lines
Well Location
Outcrop Location
Nan Clastics
Clastic Rotio
Sandstone
Shale

into the Michigan Basin where local depositional thickening has produced a maximum thickness of 600 feet.

In Late Devonian time the elongate Appalachian Basin roughly paralleled the NE/SW trend of the present-day Appalachian Mountains, and extended from southwest Virginia to New York State. Thicknesses of 9000+ feet have been recorded close to the eastern erosional edge of the unit in NE Pennsylvania. However, the isopach pattern, which shows no evidence of eastward thinning, indicates that even thicker deposits may once have been present closer to the Acadian Mountain source. The northern limit of the Appalachian Basin is also one of erosion. Here, however, isopach lines roughly parallel the zero edge since their construction has been greatly influenced by data derived from partial sections. There is neither marked depositional thinning nor deflection of the lithofacies pattern; therefore, it seems reasonable to assume that Upper Devonian sediments were deposited well to the north of this zero edge and have since been removed by erosion. To the west, the isopach pattern parallels the zero edge of the basin and depicts the gradual thinning of the clastic wedge toward the Cincinnati Arch. It is probable that a thin veneer of Upper Devonian sediments (Ohio Shale, Chattanooga Shale, and equivalents) were deposited across the top of the Cincinnati Arch and since have been removed by erosion. This hypothesis is supported by the presence of similar sediments on both the eastern and western sides of the arch. Furthermore, lithologic evidence of shoreline conditions is lacking, indicating that the Cincinnati Arch probably was not an active positive element during deposition of Upper Devonian sediments.

LITHOFACIES PATTERN

The lithofacies pattern graphically shows the continuous gradation from sand in the east, through sand-shale and shale-sand, to shale in the west. This distribution indicates the presence of a major positive source in the east, and is evidence for the major pulse of organic activity, known as the Acadian Orogeny, which commenced in the Late Devonian and continued after the termination of the Devonian Period. It is interesting to note that only a surprisingly small area in southeastern Pennsylvania represents the sand end-member (79% sandstone), and that no linear belt of predominantly coarse clastics can be outlined. It seems probable that the source area was not in the immediate vicinity of the erosional edge, but rather at some distance to the east or southeast.

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Sediment Dispersal Patterns within the Catskill Facies of Southeastern New York and Northeastern Pennsylvania

ABSTRACT

Patterns of sediment dispersal have been determined for three stratigraphic intervals within the Catskill facies of southeastern New York and northeastern Pennsylvania. Cross-bedding of the festoon type was the principal current structure utilized although the orientations of parting lineations, ripple marks, flute casts, and groove casts were also measured and analyzed. Sediment transport as indicated by cross-bedding orientations was from east to west for the region as a whole, and possessed greater lateral variability within each stratigraphic interval than between them. The maximum thickness of cross-bed sets was measured and has been found to increase toward the source area.

INTRODUCTION

Primary current structures such as cross-bedding and sole marks have been widely and successfully utilized during the past decade in reconstructing sediment dispersal patterns and in determining the nature of their attendant hydrologic regimes. Within the central Appalachian Basin studies of this type have been or are in the process of being carried out for fluvial sandstones of every age represented and for some of the marine strata (Pettijohn, 1962).

Previous investigations of Devonian paleocurrents in Pennsylvania and New York have been almost wholly limited to the marine facies (Sheldon, 1929; Colton and de Witt, 1959; Sutton, 1959; and McIver, 1961). Both McIver and Pelletier (1958) have measured the orientation of primary current structures in the Catskill facies of central Pennsylvania, and McIver has sampled some scattered localities in New York. In both cases, however, all paleocurrent data were analyzed without regard to their position within an eastward thickening clastic wedge whose greatest cumulative thickness exceeds 8,000 feet. Although it has been demonstrated that paleocurrent systems commonly remain stable throughout long periods of time (Pettijohn, 1962), vertical variations in the Devonian paleocurrent system of the central Appalachians have been detected.

Sheldon (1929) studied ripple mark orientations in the Ithaca Formation around Cayuga Lake and noted that the northeasterly source of supply

indicated by ripple marks near the base of the formation gradually shifted to a more easterly source for the sandstones and shales higher in the formation. Sutton (1959) utilized variations in the orientation of sole marks as an aid in correlating Upper Devonian marine units in central New York. Colton and de Witt (1959) have reported that sole marks in western New York indicate that transport of the clastics which comprise the Genesee Group was from the northeast, and gradually shifted from east-northeast in early Sonyea time to east-southeast in late Sonyea time. Vertical variations in the orientation of primary current structures in the Portage and Chemung facies of central Pennsylvania have been recorded by McIver (1961). Thus it is apparent that in this study of the sediment dispersal patterns within the Catskill facies a test for change in sediment transport trends with time should be made.

REGIONAL SETTING

The 7,000 square miles which this investigation include lie astride the northeastern-most portion of the Allegheny Plateau where it is locally known as the Pocono Plateau in northeastern Pennsylvania and has been highly dissected in southeastern New York to form the Catskill Mountains. The study has been extended so as to include the nonmarine equivalents of the Catskill facies preserved in the Skunnemunk Outlier near the New York-New Jersey border. The grid in Figure 1 and the succeeding diagrams outlines the study area.

The strata of this region have been warped into a broad southwest-plunging synclinorium. Structural dips generally do not exceed 5 degrees except in the tightly folded beds of the Skunnemunk Outlier, at places along the eastern margin of the synclinorium, and on the flanks of north-northeast trending flexures within the synclinorium. The largest of these structures is the Lackawanna syncline which extends north-northeast from the vicinity of Scranton, Pennsylvania and dies out just south of the state line.

To the west, north, and east, the Catskill facies passes either vertically or laterally into marine strata of the Chemung facies. Thus in moving north or east down the stratigraphic section, one encounters the same depositional environments that one would by moving westward along some time plane. This fact explains several of the anomalous trends in the paleocurrent indicators near the margins of the region.

ACKNOWLEDGEMENTS

This paper represents a portion of an integrated paleocurrent and petrographic study which is to be submitted as a Ph.D. dissertation to the Department of Geological Sciences at Harvard University in 1963. The

guidance of Dr. Raymond Siever who has served as the writer's adviser and read the manuscript is gratefully acknowledged. The writer has also benefited from discussions with Dr. Lawrence V. Rickard, Dr. Robert G. Sutton, Mr. Douglas Glaeser, and others who have been working on problems of Devonian stratigraphy in and adjacent to the area covered by this report.

Work was begun in the summer of 1960 during the tenure of a National Science Foundation Fellowship and has subsequently been supported by grants and fellowships from Harvard University, the National Science Foundation, and the New York State Museum and Science Service.

The Computation Center at the Massachusetts Institute of Technology granted permission to use the IBM 7090 computer for calculating current orientation vectors. Miss Carol A. Spitzer aided in drafting one of the figures.

PRIMARY CURRENT STRUCTURES

Cross-bedding, parting lineations, ripple marks, flute casts, and groove casts are the primary current indicators whose orientations were measured for this study. Data for each are plotted in Figures 1,3, and 5.

Cross-bedding is the single most abundant paleocurrent indicator in the Catskill facies. In all adequately exposed outcrops, the cross-beds proved to be of the festoon type. In plan view the festoons are semi-ellipsoidal in shape, the convex portion pointing in the upstream direction. Foreset planes are sharply truncated at their upper ends and form a nearly tangential contact with underlying beds.

Parting lineation (Crowell, 1955) or primary lineation (Stokes, 1947) was commonly observed in the even-bedded sandstone which at places is interlayered with cross-bedded sandstone. Parting lineation orientations are parallel to the current trends delineated by other structures and have been found to be related to the preferred orientation of sand grains (Yeakel, 1959; McIver, 1961). Parting lineation is the prevalent current structure in the flagstone quarries along the western margin of the area.

Three types of ripple marks other than interference ripple marks were observed, none of which are widely distributed. Symmetrical and asymmetrical ripple marks arranged in sub-parallel ridges of low amplitude are limited to fine-grained red and green sandstones where they are transitional between the marine and nonmarine facies. Barchan or cuspate ripple marks were found at only one locality. They appear to be a microscale variety of the scalloped sandwaves which are related to festoon cross-bedding (Niehoff, 1959).

Elongate bulbous structures common to the base of sandstone beds which overlie shale differ from flute casts only in not flaring and merging with the bedding plane in the down current direction.

Groove and striation casts are sole markings common to the lower surface of marine sandstones overlying shales. They are "raised, straight linear features which appear to be sand-filled grooves or striation in the underlying mud surface" (Pettijohn, 1962). No groove casts were seen in the Catskill facies by the writer, but orientations measured by McIver (1961) in marine strata adjacent to this area have been plotted.

STRATIGRAPHIC DIVISIONS OF THE CATSKILL FACIES

It is not the purpose of this paper to define any new stratigraphic units within the Catskill facies or to propose any new correlations. In order to map changes in sediment dispersal patterns with time, the Catskill facies has been divided into three stratigraphic intervals whose limits, it is hoped, roughly approximate time lines. In establishing these stratigraphic intervals an attempt has been made to include roughly equal thicknesses of strata within each and therefore roughly equal amounts of time; to avoid as much as possible the serious correlation problems between New York and Pennsylvania; and to set up divisions which have significant areal distribution. The geologic maps of New York (1961) and Pennsylvania (1960) have served as the basis for all correlations and for the outcrop distribution of units within these intervals.

Interval 1 (Middle Devonian) Interval 1 includes all formations of the Catskill facies which are of Middle Devonian age (Table 1). In the Catskill Front and the Hudson River Valley of New York these units are the Ashokan and Kiskatom Formations which have a minimum thickness of 2,600 feet (Chadwick, 1944). Their equivalents in the Skunnemunk Outlier are the Bellvale and Skunnemunk Formation which reach a maximum cumulative thickness of 4,500 feet in Bearfort Mountain (Darton, 1894). A Middle Devonian age for the Skunnemunk Formation, particularly its upper portion, is uncertain. The general outcrop pattern of these strata is delineated by the distribution of paleocurrent vectors and circular histograms in Figure 1.

Interval 2 (Upper Devonian) This stratigraphic interval includes the Oneonta and Stony Clove Formations and their equivalents. West of the highest Catskill peaks most of the exposures within this interval lie in the major southwest trending valleys and their tributary valleys. Although the greatest cumulative thickness of the formations in this division probably nowhere exceeds 2,500 feet, placing the upper limit at the top of the Stony Clove Formation and its equivalents avoids the difficulty of dividing the Catskill Formation of the Pocono Plateau above the valleys of the Delaware and Lackawaxen Rivers.

Interval 3 (Upper Devonian) Interval 3, the highest stratigraphic division, embraces the Katsberg and Slide Mountain Formations in New York and

		New York State		Pennsylvania		New Jersey
Upper Devonian	Interval 3	Upper Sonyea, Java & West Falls Gps.	Slide Mountain Formation Katsberg Formation	Susquehanna Group	Catskill Formation	
	Interval 2	Genesee and lower Sonyea Groups	Stony Clove Formation Oneonta Formation Kaaterskill Formation		Catskill Formation	
Middle Devonian	Interval 1	Hamilton Group	Kiskatom Formation Ashokan Formation			Skunnemunk Formation Bellvale Formation

Table 1. Divisions of the Catskill facies in this report.

all nonmarine equivalents of the Susquehanna Group in northeastern Pennsylvania with the exception of the basal portion which has been correlated with the Stony Clove Formation of New York (Geologic Map of New York, 1961). The maximum thickness of the strata within this in interval is uncertain. In the Moscow 7½′ quadrangle near the Lackawanna syncline a gas storage well of the Transcontinental Production Company, Schreiber #1, has penetrated 4,971 feet of the Catskill facies, a substantial percentage of which probably falls within Interval 3. Farther east and northeast of the Lackawanna syncline, however, erosion has substantially reduced this thickness.

SAMPLING

In order to obtain a relatively even distribution of sample localities throughout the area, the selection of exposures for measuring the orientation of cross-bedding was predetermined for each stratigraphic interval by a grid of six mile square units. These units correspond in area to survey townships and for convenience will be referred to as such.

Sampling within townships was carried out in a manner similar to that performed for the Caseyville and Mansfield Formations of the Illinois Basin (Potter and Olson, 1954). Within each township two outcrops were selected for the representatives of each stratigraphic interval. Occasionally only one exposure could be found, and in a few townships as many as four exposures were sampled within one interval. Approximate randomization of choice of exposures was achieved by selecting the first exposure encountered in a township, and where outcrops were plentiful, by accepting the second one only if it were at least one mile from the first.

Originally two or five of the best-defined, most accessible cross-bed sets were selected at each exposure in the Middle Devonian of the Catskill Front, but a comparison of the sediment dispersal patterns for Interval 1 based on orientations from five cross-bed sets at most exposures did not differ appreciably from transport trends defined by orientations from but two sets at each exposure. Thereafter rarely more than two cross-bed sets were sampled at each locality. Within each cross-bed set two foreset measurements were taken as far apart as possible in order to minimize the bias resulting from excessive sampling of the limbs of the festoons. Wherever festoon axes were exposed on a bedding plane, the down current azimuth of each axis was recorded twice because of its greater reliability as a paleocurrent indicator and in order to insure that each cross-bed set would contribute equally to the total sample.

In most cross-bed sets it was possible to measure directly the azimuth of the maximum dip direction. In a few outcrops it was necessary to measure the orientation of the apparent foreset dip on two faces and reconstruct the maximum dip direction on a stereographic net. Wherever

structural dips exceeded six degrees the dip azimuths were corrected for folding by rotation about the strike of the bedding.

A measurement of the maximum dip inclination was recorded in addition to each foreset orientation. The maximum thickness of each cross-bed set was determined where exposure of the set was complete.

The vector mean current direction and consistency ratio were calculated trigonometrically (Curray, 1956) for each locality with the aid of an IBM 7090 computer. Local irregularities were eliminated and regional trends emphasized by constructing moving average maps for each stratigraphic interval. This operation was performed by giving equal weight to all locality vector means and then summing trigonometrically all the locality vector means within two to four mutually adjacent townships. The resulting moving average vector has been designated by an arrow plotted at the point of intersection of the townships. The grand mean and consistency ratio for each stratigraphic interval as a whole was computed by extending this summation process to all weighted locality vector means. Because weighted samples were used in this summation process, the effective sample size generated rather than the actual number of cross-bed orientations in the total sample had to be used in calculating the consistency ratio.

DISPERSAL PATTERNS

The vector means for each type of primary current structure has been plotted at all localities at which they were measured. These vectors are presented on three maps (Figures 1, 3, and 5), and corresponding moving average maps of cross-bed vector means are presented for each stratigraphic interval (Figures 2, 4, and 6).

Interval 1 (Middle Devonian) Figure 1 depicts average flow directions at each exposure in Interval 1. Both the consistency ratio and the standard deviation have been calculated and are listed in Table 2.

The best estimate of sediment transport trends in the Middle Devonian is the moving average map in Figure 2. Subregional trends are readily apparent on this map in which irregularities at the outcrop and township level have been eliminated. Consistency of sediment transport from the east-northeast is shown by the arrows in the northern portion of the area. To the south uniformity of transport from the east and east-southeast is evident.

The linear shape of the Skunnemunk Outlier has made it necessary to treat paleocurrent data from it in a different manner. A circular histogram of the average, tilt-corrected, cross-bed set dip azimuths has been plotted at each locality with an arrow representing the locality vector mean. The three southern localities are located slightly above the Skunnemunk-Bellvale contact on the vertical to slightly overturned eastern limb of the doubly plunging syncline which forms Bearfort Mountain. No cor-

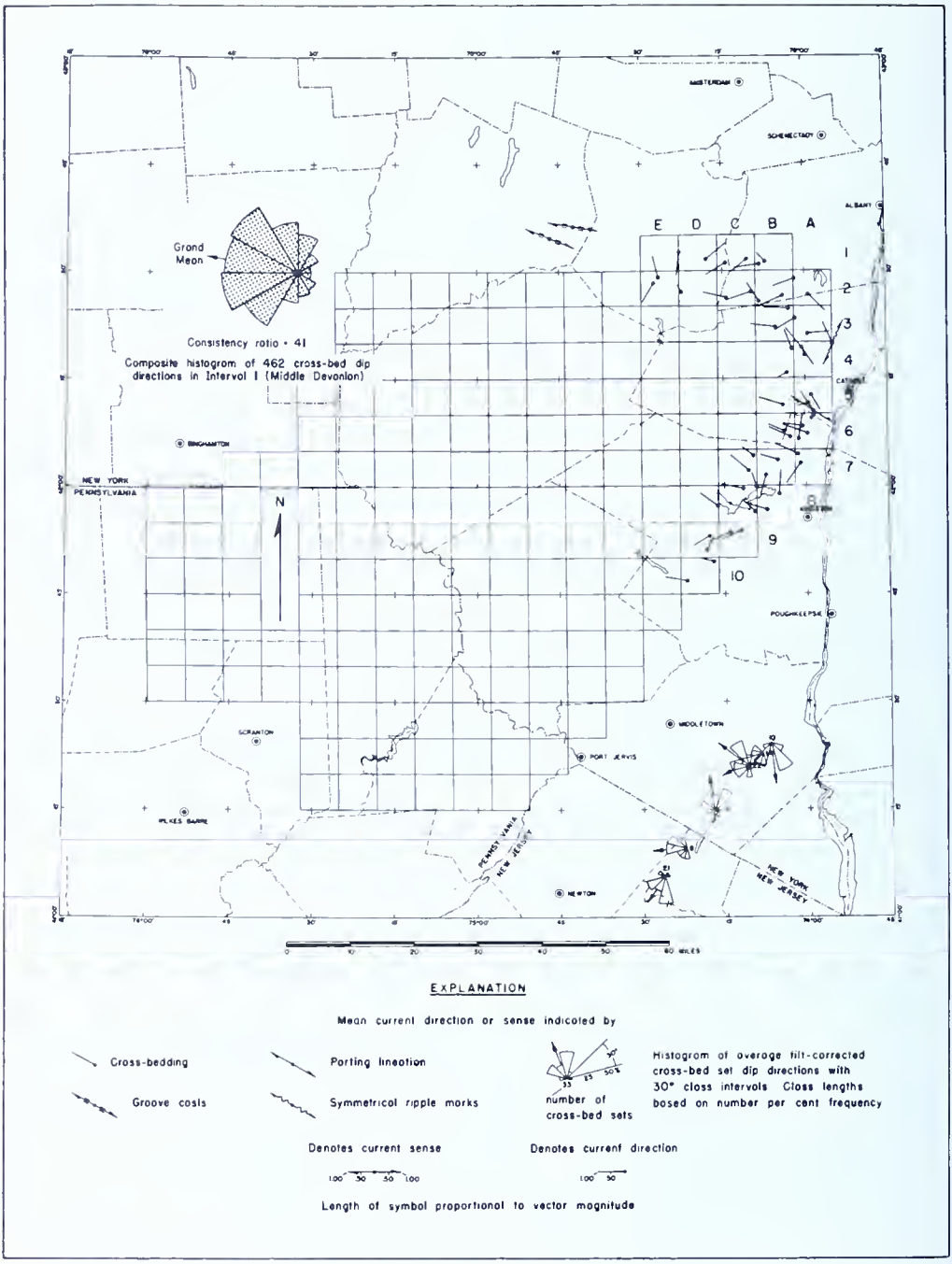

Figure 1. Catskill vectar means in Interval 1 (Middle Devanian) and circular histagrams af crass-bed set distributian in the Skunnemunk Outlier.

Stratigraphic Interval	Actual Number of cross-bed orientations	Position of Origin	Standard Deviation	Effective No. of cross-bed orientations	Mean Current Direction	Consistency Ratio
Interval 1	462	90°	77°	530	281°	.41
Interval 2	781	90°	73°	572	273°	.51
Interval 3	1030	120°	72°	1032	286°	.45

Table 2. *Summary of Cross-bed Data for Grid.*

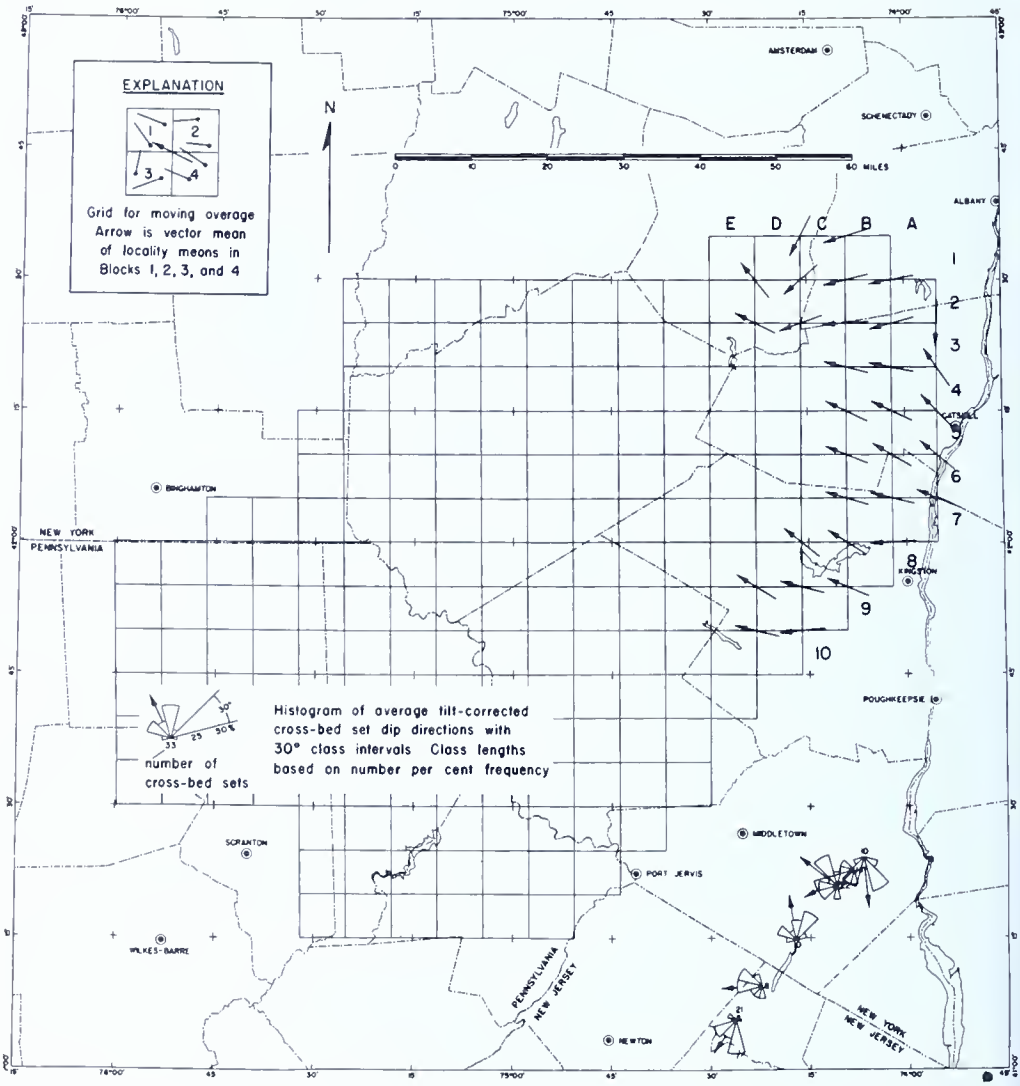

Figure 2. Moving average of Catskill cross-bed vector means in Interval 1 (Middle Devonian) and circular histograms of cross-bed set distribution in the Skunnemunk Outlier.

rection for the plunge of the fold has been made in the paleocurrent orientations because it is estimated that the plunge is less than 10°. It is suggested that the large variance in cross-bedding between these three exposures and the geographic distribution of the vector means may have been created by dispersal of sediment across the slopes of an alluvial fan.

Subangular to well-rounded quartz and quartzite pebbles within the Skunnemunk Formation are commonly 4 to 6 inches long in the southern three localities. In the northern-most locality of the outlier, similar pebbles near the base of the Skunnemunk Formation are as much as 8 to 12 inches in diameter. Studies of the maximum pebble sizes deposited on modern alluvial fans (Blissenbach, 1954) indicate that subangular to

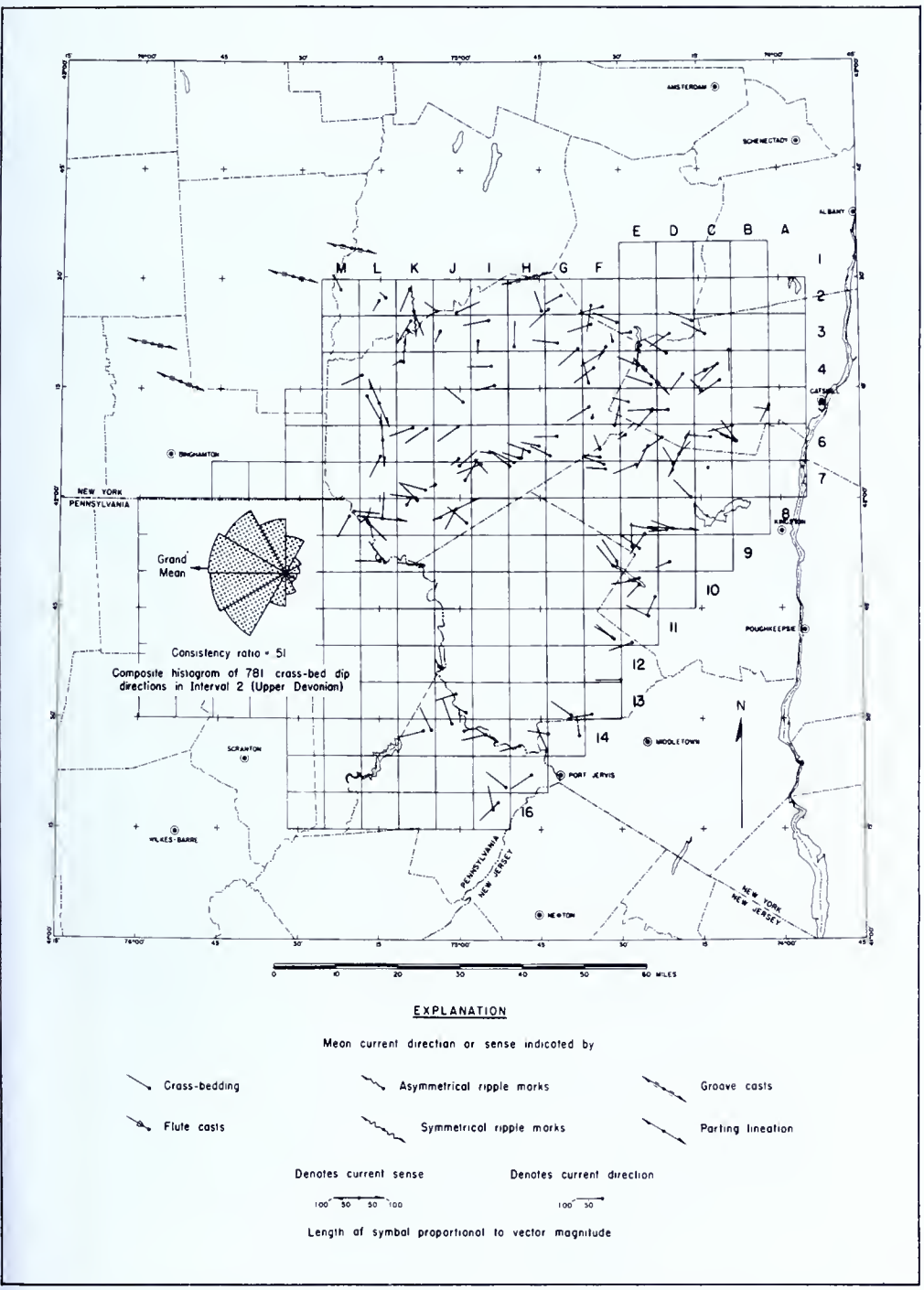

Figure 3. Catskill vector means in Interval 2 (Upper Devonian).

rounded pebbles of this size have not moved more than a few miles from the basinward limits of the source area.

Local deviations of the paleocurrent indicators from the regional westerly dip of the paleoslope were most likely produced by local irregularities imposed by alluvial fans or by irregularities within the source area itself. It is believed that either one or both of these possibilities may adequately explain the dispersal pattern near the northern limit of the outlier.

Interval 2 (Upper Devonian) Vector means for the lowest division of the Upper Devonian (Figure 3) show considerable scatter, but generally point to the southwest, west, and northwest. The moving average (Figure 4)

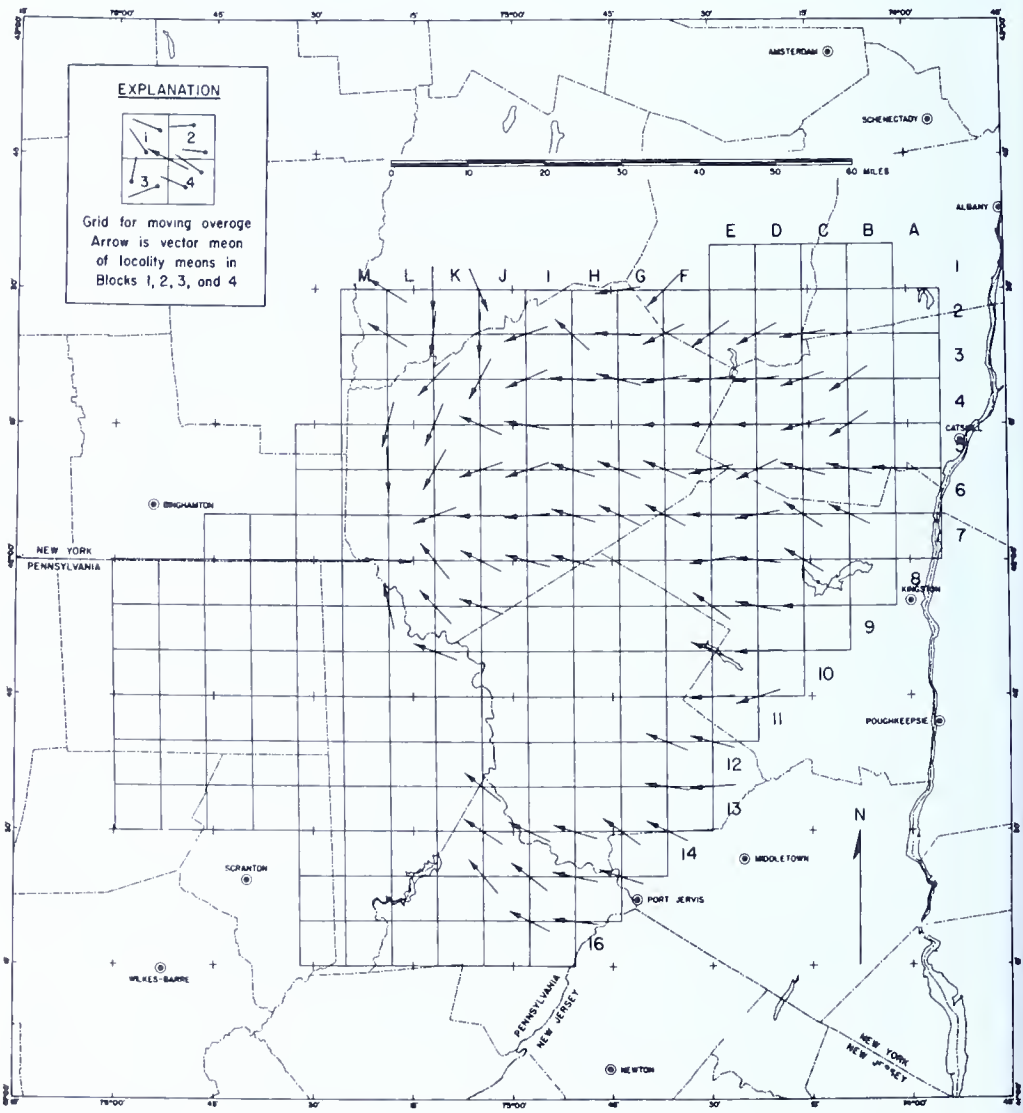

Figure 4. Moving average of Catskill cross-bed vector means in Interval 2 (Upper Devonian).

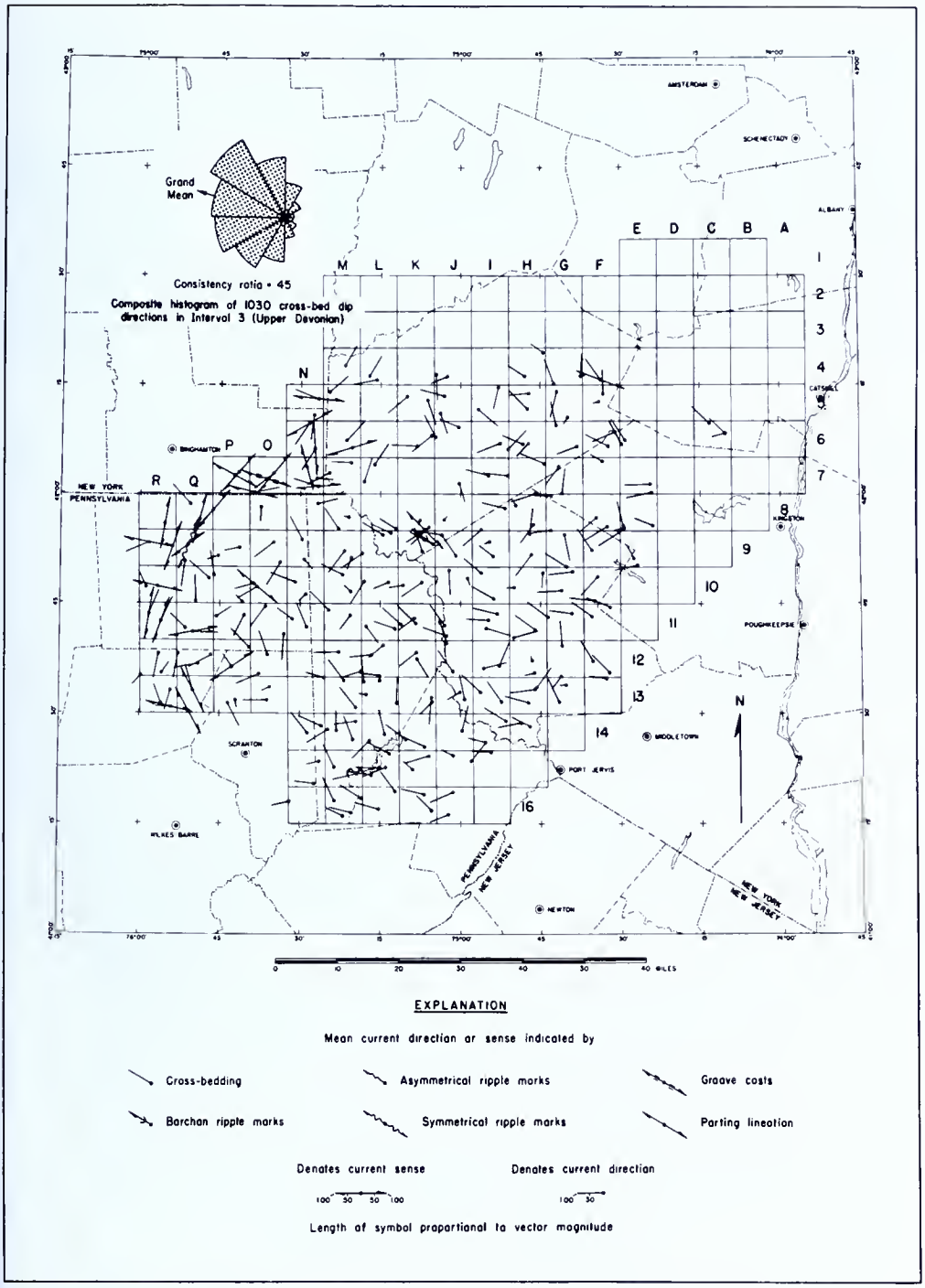

Figure 5. Catskill vector means in Interval 3 (Upper Devonian).

shows a pattern of sediment transport similar to that in the Middle Devonian. One difference is that the east-northeast to west-southwest paleocurrent trends persist slightly beyond their southern limit in Interval 1.

Interval 3 (*Upper Devonian*) Cross-bed vector means in Figure 5 possess predominantly southwesterly, westerly, and northwesterly components. Parting lineation is highly consistent in its orientation within an outcrop. Where it is abundant in the flagstone quarries along the western margin of the area it defines two strong trends. One trend is transverse to the westerly dip of the paleoslope and is thought to represent littoral marine transport of the sand by longshore currents (Burtner, 1963). The second

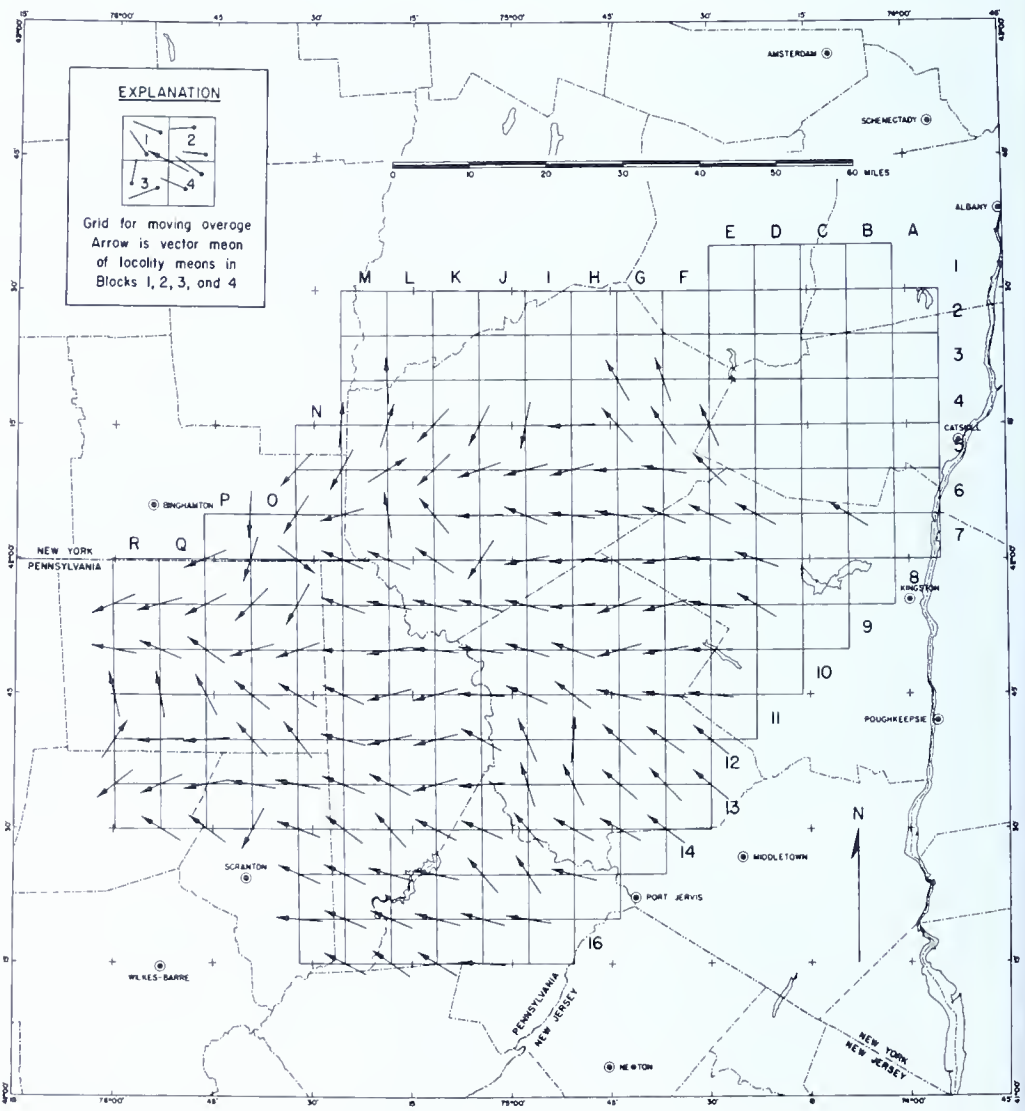

Figure 6. Moving average of Catskill cross-bed vector means in Interval 3 (Upper Devonian).

trend is nearly everywhere transverse to the first and is thus parallel to the offshore dip of the depositional surface.

The moving average of the cross-bed orientations clearly show an east to west direction of sediment transport across the central portion of the area and an east-southeasterly source of supply for the southern portion. Moving average arrows in the northwestern third of the area possess great variability in both Intervals 2 and 3. Complete reversals of adjacent arrows indicate that the variance of cross-bed orientation between townships and possibly between outcrops within townships is greater than in other areas. This abrupt increase in the variability of paleocurrent direc-

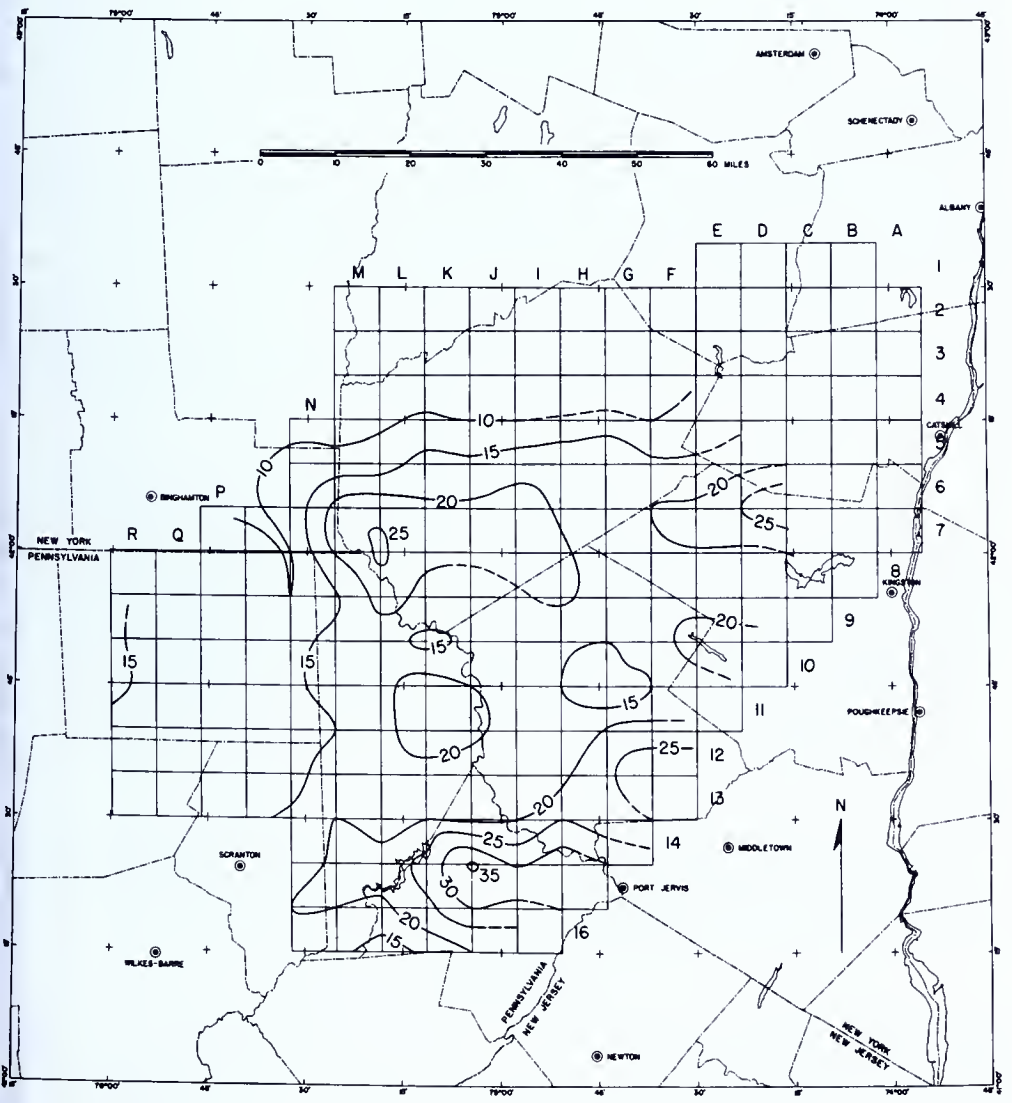

Figure 7. Moving average map of Catskill cross-bedding thickness. Contour interval equals 5 inches. Isopleth is dashed where inferred.

tions is related to the proximity of the localities to strata of unquestionable marine origin and probably was produced by formation of the cross-beds within a tidal or littoral marine environment at the edge of the Catskill alluvial plain.

No downcurrent decrease in vector magnitude that could be attributed to an increase in meandering of the ancient streams is evident. It may be, however, that not enough orientations were taken at the outcrop level to detect such changes.

A contoured, moving average map of cross-bed thickness (Figure 7) was prepared for Interval 3. It is evident that cross-bed thickness increases toward the source and that the east-west trends are nearly parallel to the moving average vector means in Figure 6. Although an increase in the thickness of cross-bedding with increasing proximity to the source area has been noted for the Catskill facies farther south (McIver, 1961), for the Pocono Formation of Pennsylvania (Pelletier, 1958), and for the Lower Cretaceous sands of East Anglia (Schwarzacher, 1953), other formations such as the Tuscarora do not show such trends (Yeakel, 1962). Knowledge of the genesis of festoon cross-bedding is not sufficiently complete to permit interpretation of this phenomenon. The relation or lack of it between rates of subsidence, ratio of flood plain deposits to channel sandstones, and thickness of cross-bedding may be significant, but the data required for making such comparisons is either nonexistent or insufficiently detailed in this area.

CONCLUSION

The sediment dispersal trends established for this area at the beginning of the Acadian orogeny persisted with but minor changes throughout Upper Devonian time. Sediment was transported into the area from a linear source which lay to the east-northeast and east-southeast during the Middle and early Upper Devonian. Data from the northeastern portion of the area is meager for the highest stratigraphic interval. Thus it has been impossible to determine if sediment from the east-northeastern source continued to be contributed to the area throughout the Upper Devonian.

Sediment dispersal trends possess greater lateral variability within a stratigraphic interval than between intervals. Subregional differences in cross-bed variance are thought to have environmental significance.

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Regional Stratigraphy of Middle and Upper Devonian Non-marine Rocks in Southeastern New York

ABSTRACT

The stratigraphy of the Middle and Upper Devonian non-marine rocks of southeastern New York, founded upon biostratigraphic and time-stratigraphic criteria, is inadequate and, in many cases, erroneous. A new standard of stratigraphic nomenclature is presented that permits the definition and tracing of units in the field and the subsurface. This scheme is based upon lithologic features such as rock type, color and sedimentary structures.

Approximately 6,000 feet of interbedded red and gray shale, claystone, siltstone, sandstone and conglomerate overlie the Ashokan Formation in southeastern New York. This sequence is subdivided into the following units: Plattekill, Gilboa, Oneonta, Twilight Park-Kattel, Walton and Wittenberg Formations. These formations are correlated with marine strata in south-central New York.

INTRODUCTION

Classical studies of the stratigraphy of the late Middle and Upper Devonian in southeastern New York have been based ultimately upon biostratigraphic and time-stratigraphic principles (Hall, 1885; Williams, 1887; Prosser, 1891; Stevenson, 1891; Cooper, 1934, 1941; Chadwick, 1933b). The stratigraphic nomenclature that evolved from these investigations is founded upon faunal zones and "time-planes" extrapolated from the marine facies to the non-marine. These criteria proved unsatisfactory because of the complex and shifting facies changes of both lithologies and fauna. Attempts at regional lithostratigraphic subdivision of similar age rocks in northeastern Pennsylvania, likewise met with little success (White, 1881, 1882; Willard, 1936). The nomenclature often is erroneous even at the type locality, eg. Delaware River flags (Willard, 1936) and Stony Clove sandstone (Chadwick, 1944); and is meaningless when extended to outcrops in adjacent regions or into the subsurface.

The present study provides a new standard of stratigraphic nomenclature for the Devonian non-marine facies of New York. New rock units have been defined and miscorrelations with marine formations in south-central New York have been corrected (Fig. 1). The utility of the

scheme permits one to distinguish and trace the units in the field and in the subsurface, heretofore impossible. This investigation is based on work performed in 1960 through 1963 under the auspices of the New York State Museum and Science Service whose assistance is gratefully acknowledged.

The study area is situated in southeastern New York, approximately 70 miles northwest of New York City and 25 miles southwest of Albany. It occupies more than 4000 square miles and contains all of the rocks ascribed, at one time or another, to the *Catskill* of New York State. More precisely the area includes all or parts of 25 U. S. Geological Survey 15-minute topographic sheets and is bounded by the latitudes 41°15′ N and 42°30′ N and by the longitudes 73°45′ W and 75°30′ W (Fig. 2).

STRATIGRAPHY

General Remarks

Lithologically the strata consist of interbedded red shale, claystone, siltstone, sandstone and conglomerate; green shale and sandstone; and gray shale, sandstone and conglomerate. They have a maximum thickness of approximately 6,000 feet (Fig. 3) and range in age from late Middle Devonian to middle Late Devonian. Units of the study area have been defined and correlated upon lithologic features. These include: color, rock type and sedimentary structures.

1. Zones of red beds were employed successfully in subdivision and in correlation with formations outside the region because they are the most distinctive strata in outcrop, are readily identified in well samples, and lie stratigraphically parallel with the black shales which have been used to correlate the strata of western and south-central New York (Fig. 4, see also: Sutton and others, 1962, p. 391–393). Isopachous lines constructed for the stratigraphic interval between the Onondaga Limestone and the Oneonta Formation trend N 80° W. Maximum thickening occurs S 10° W. (Fig. 5). If the position of the Onondaga and the thickness of the marine interval are known, it is possible to identify any red tongue by calculating the depth between the outcrop and the Onondaga.

2. Although possible confusion may lie in mistaking one red tongue for another in areas where subsurface evidence is absent, stratigraphic position can be estimated on the basis of the associated sandstone or conglomerate type (Fig. 3).

3. Thin, dark-gray shales, easterly extensions of the black shales that subdivide the south-central New York strata, are key beds which serve to partition the eastern section (Fig. 6, 7). The positions of these horizons are marked by a significant change in the orientation of current structures (Fig. 3).

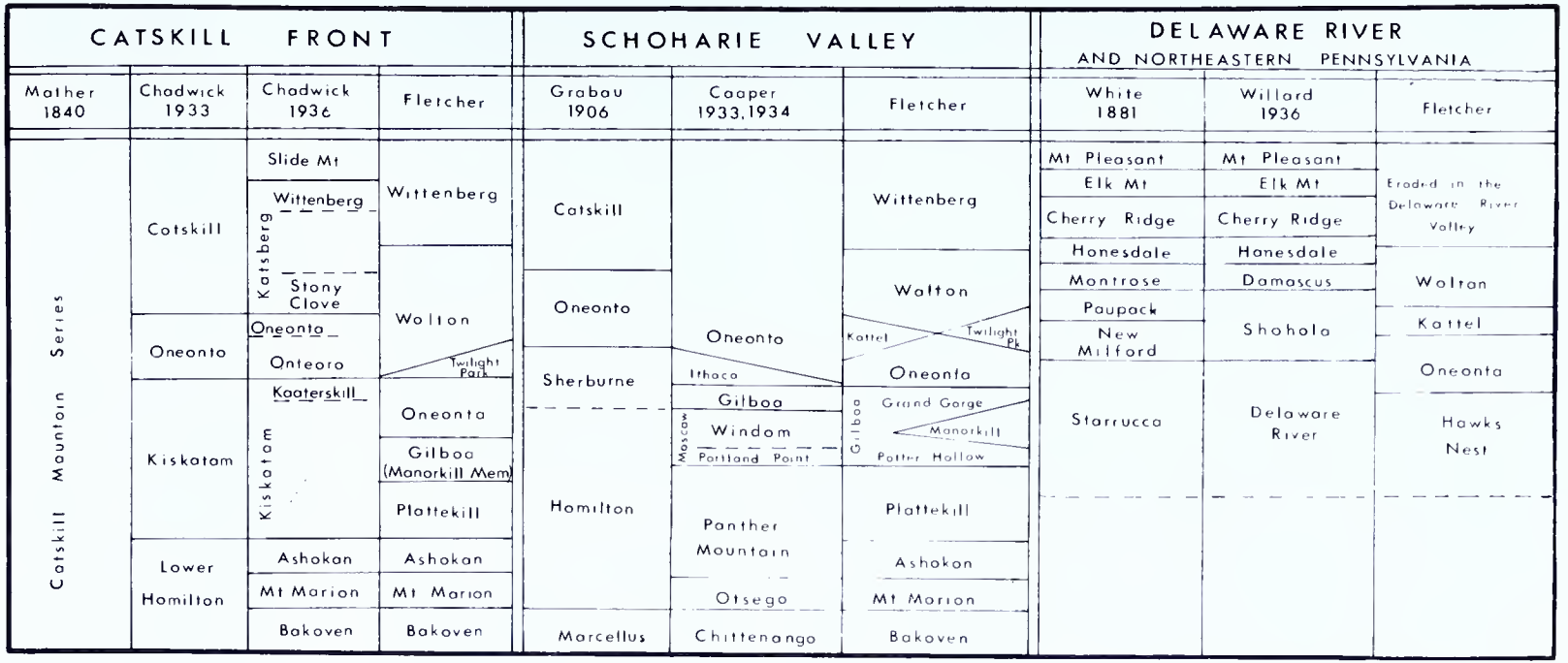

Figure 1. Comparison of stratigraphic nomenclature employed for Middle and Upper Devonian strata in southeastern New York.

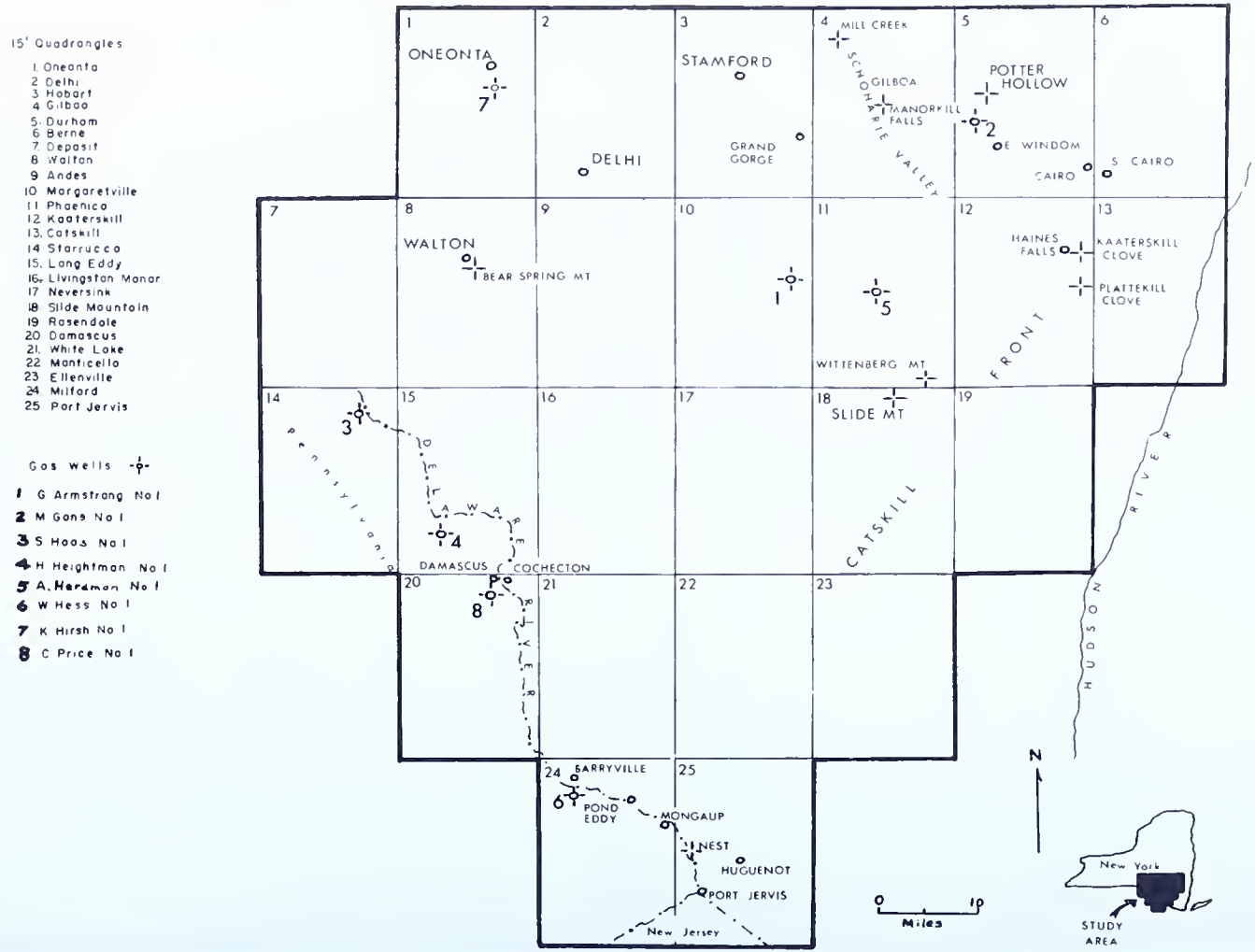

Figure 2. Study area

Plattekill Formation

The Plattekill Formation is named for exposures in Plattekill Creek at West Saugerties (Kaaterskill quadrangle). The name was introduced to replace, in part, "Kiskatom" which was employed by Chadwick (1933, p. 482) for alleged Hamilton non-marine strata (Fletcher *in* Valentine and others, 1962, p. D3). The Plattekill consists of grayish-red-purple claystones and siltstones, medium-gray and medium-dark-gray shales and fine-grained (modal class: less than 0.05 mm.), cross-bedded subgraywackes. The sandstones are firmly indurated by carbonate cement. The Plattekill is the oldest unit of the Devonian section in southeastern New York that contains red strata and the contact between it and the underlying Ashokan Formation is drawn at the lowest red bed.

The Plattekill is present only in the northeastern part of the study area. Its outcrop belt extends roughly from the Schoharie Creek valley southeastward along the plain at the base of the Catskill front, trends south-southeast in the vicinity of Cairo and follows a series of low ridges to Rondout Creek. In the Phoenicia quadrangle the unit attains a maximum thickness of 860 feet. It thins to 309 feet in the Durham quadrangle and wedges out in the Schoharie valley where thin red beds occur in a series of strata assigned by Cooper (1933, p. 550–551) to the Panther Mountain Formation. In the Margaretville quadrangle the Plattekill is 113 feet thick (Fig. 6).

The contact between the Ashokan and Plattekill Formations is exposed on Route N. Y. 23, 0.6 miles southeast of South Cairo (Coxsackie quadrangle) at an elevation of 250 feet. The Plattekill's upper contact with the overlying Gilboa Formation is drawn in Plattekill Clove at a thin, medium-dark-gray shale which crops out at 1500 feet.

Fossils are rare in the Plattekill; most common are plant fragments. (For a list of species see: Chadwick, 1936, p. 91; 1944, p. 120–121.) Five species of fish have been reported from rocks which comprise the Plattekill (Chadwick, 1944, p. 120–121). Chadwick (1944, p. 120) reports finding also *Archandon catskillensis, Estheria membranacea* and "Beyrichia" sp.

Gilboa Formation

The Gilboa Formation was defined originally by Cooper (1934, p. 7–8) to include all of the rocks in the Schoharie valley between the top of the Hamilton Group and the base of the Oneonta Formation. The name "Gilboa" is employed in this report to designate the interval of rock between the Plattekill and Oneonta Formations (Fig. 4). The unit has a maximum thickness of 491 feet (Durham quadrangle) and thins to 246 and

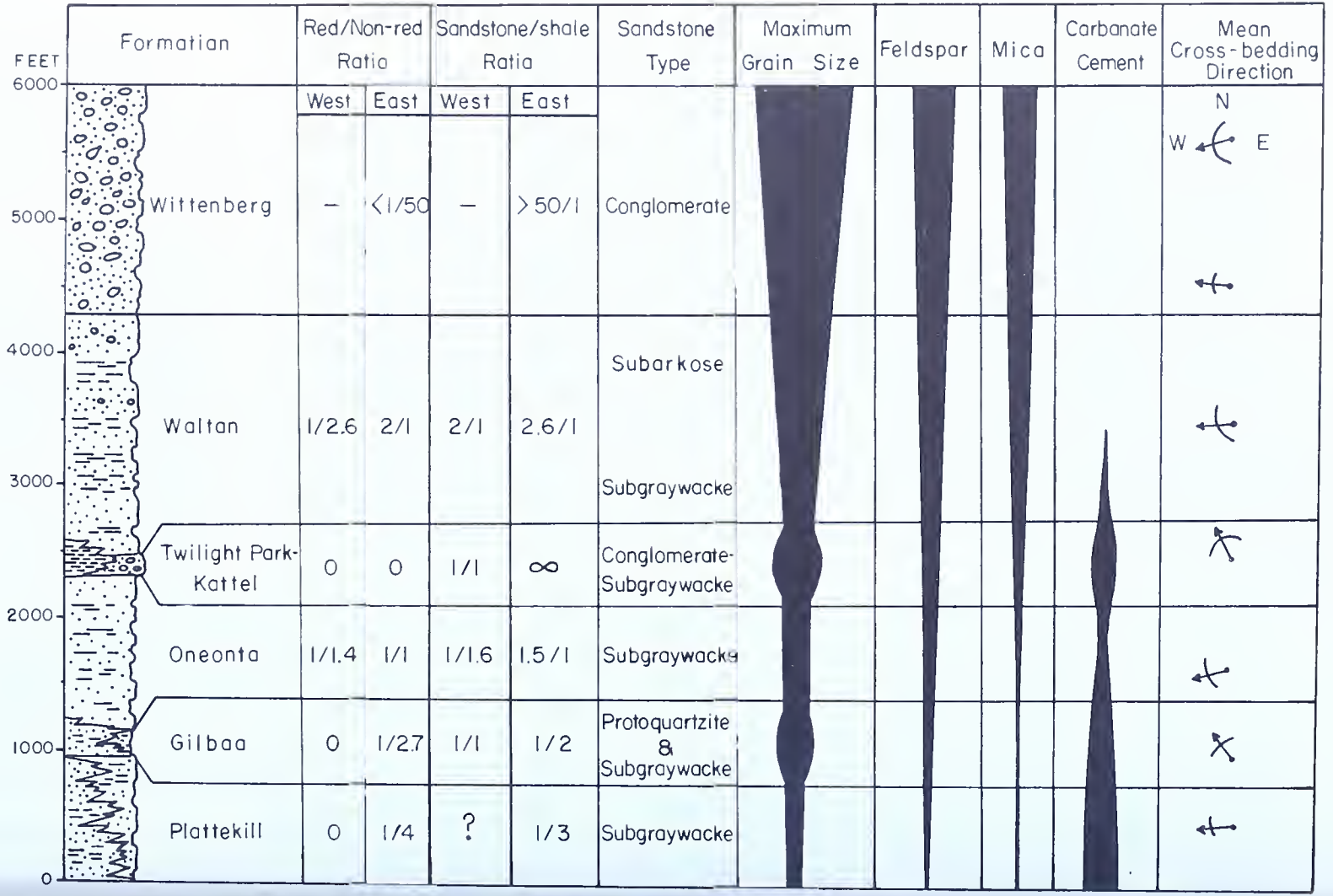

Figure 3. Gross lithologic and petrographic features of the formations.

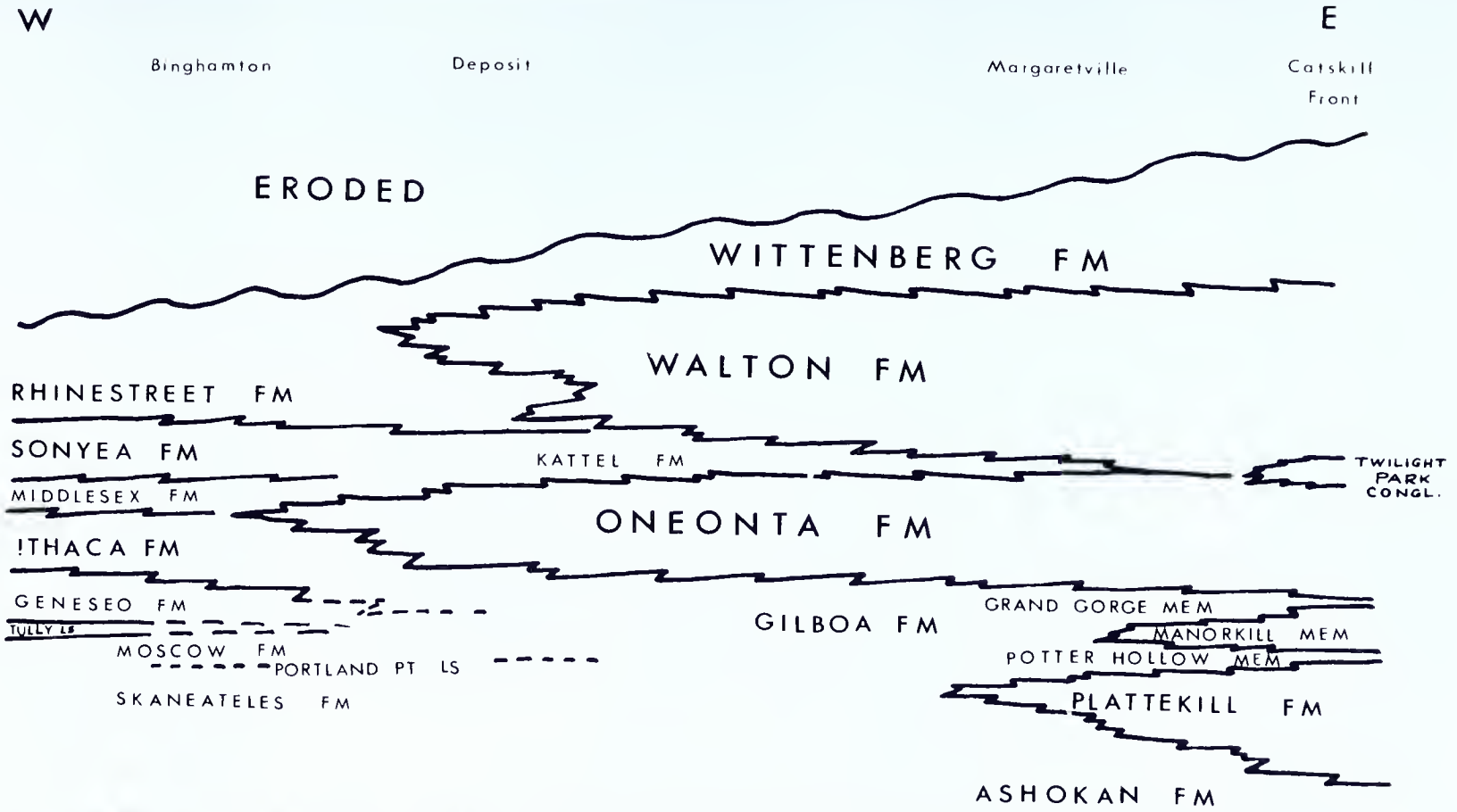

Figure 4. Correlation of the non-marine strata of the study area with the marine strata of south-central New York.

299 feet in the Phoenicia and Margaretville quadrangles respectively (Fig. 6). At the northern edge of the area, west of the Schoharie Creek valley, the Gilboa intertongues with the Moscow, Geneseo and Ithaca Formations (Fig. 4).

The Gilboa Formation is divided into three members. They are, in ascending order, the Potter Hollow, Manorkill and Grand Gorge.

Potter Hollow Member

The basal member of the Gilboa Formation, the Potter Hollow, is a sequence of thin, very light-gray protoquartzites (modal size class: 0.2 mm.), medium-dark-gray, cross-bedded subgraywackes, brown, sandy coquinites and fossiliferous medium-dark-grey shales. Cooper (1934, p. 2) called this unit the Portland Point Limestone of the Moscow Formation; but because none of the lithologic features which originally defined this interval of strata are present east of the Schoharie Creek valley, the name "Portland Point" is inapplicable there.

The type section is located along a tributary of Catskill Creek, 1.6 miles southwest of the village of Potter Hollow (Durham quadrangle) at an elevation of 1200 feet (Fig. 2). The member has been traced to the M. Gans No. 1 well, 5.7 miles south of the type locality, where 218 feet are present (Fig. 6) and along the Catskill front to Kaaterskill and Plattekill Cloves. At these last localities only thin, medium-dark-gray shales mark the position of the Potter Hollow.

Cooper (1934, p. 2) reports the following fauna from this horizon:

Vitulina pustulosa (absent in Schoharie Valley)
Centronella impressa
Eunella lincklaeni
Rhypidomella vanuxemi
Cypricardella bellistriata
Actinopteria decussata

Manorkill Member

The Manorkill Member is defined as the sequence of predominantly red sandstone and shale that lies between the Potter Hollow and Grand Gorge Members (Figs. 4, 6). At the type locality, Manorkill Falls on the east side of the Schoharie reservoir, 151 feet are exposed. These strata contain the tree-bearing sandstones of Gilboa that crop out at the level of the reservoir.

The Manorkill measures 220 feet in the Durham quadrangle (Fig. 6),

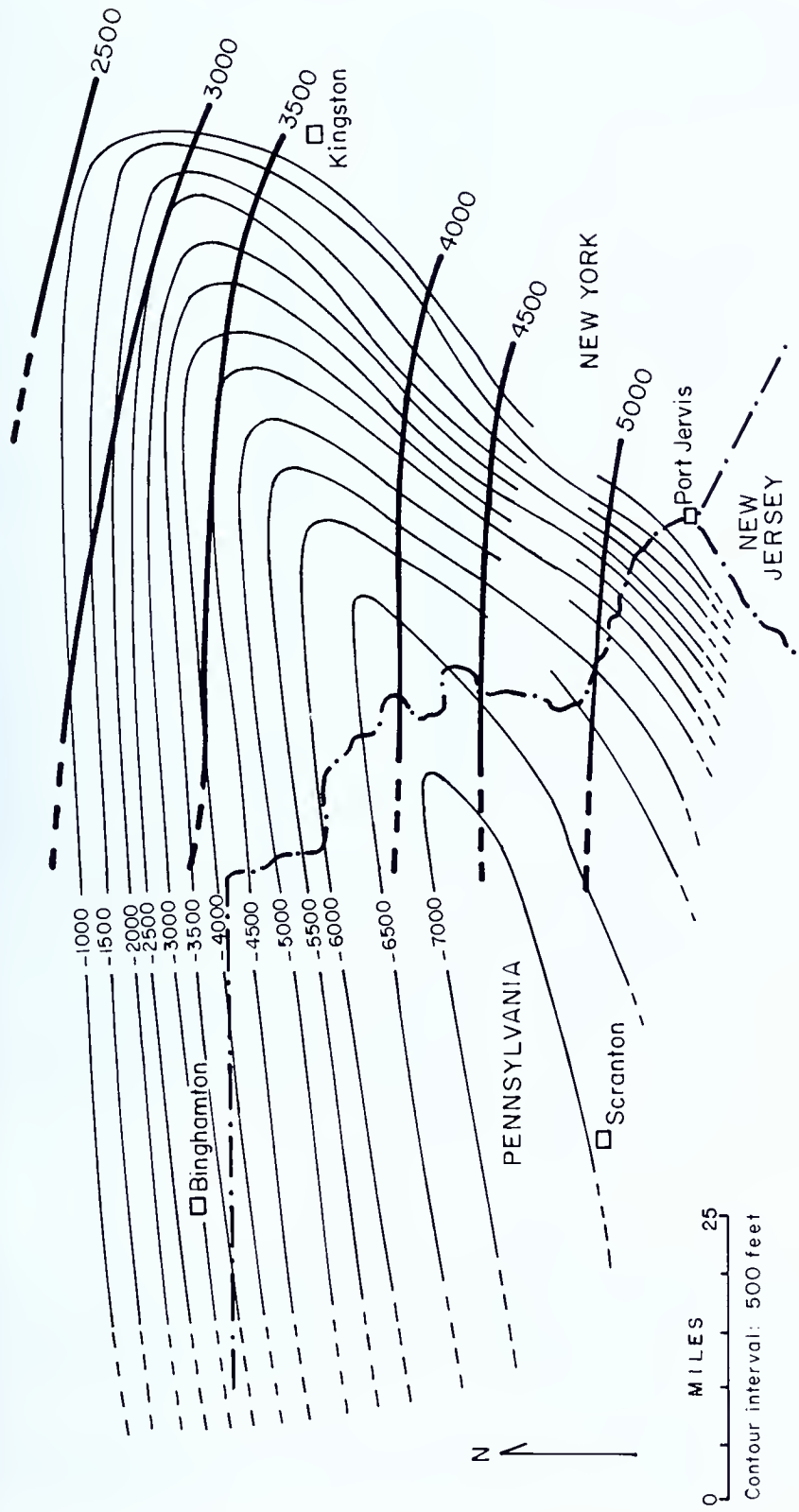

Figure 5. Structure contour map drawn on the top of the Onondaga Limestone (contour interval: 500 feet). Heavy lines are isopachous lines of the interval between the Onondaga and Oneonta Formations (contour interval: 500 feet).

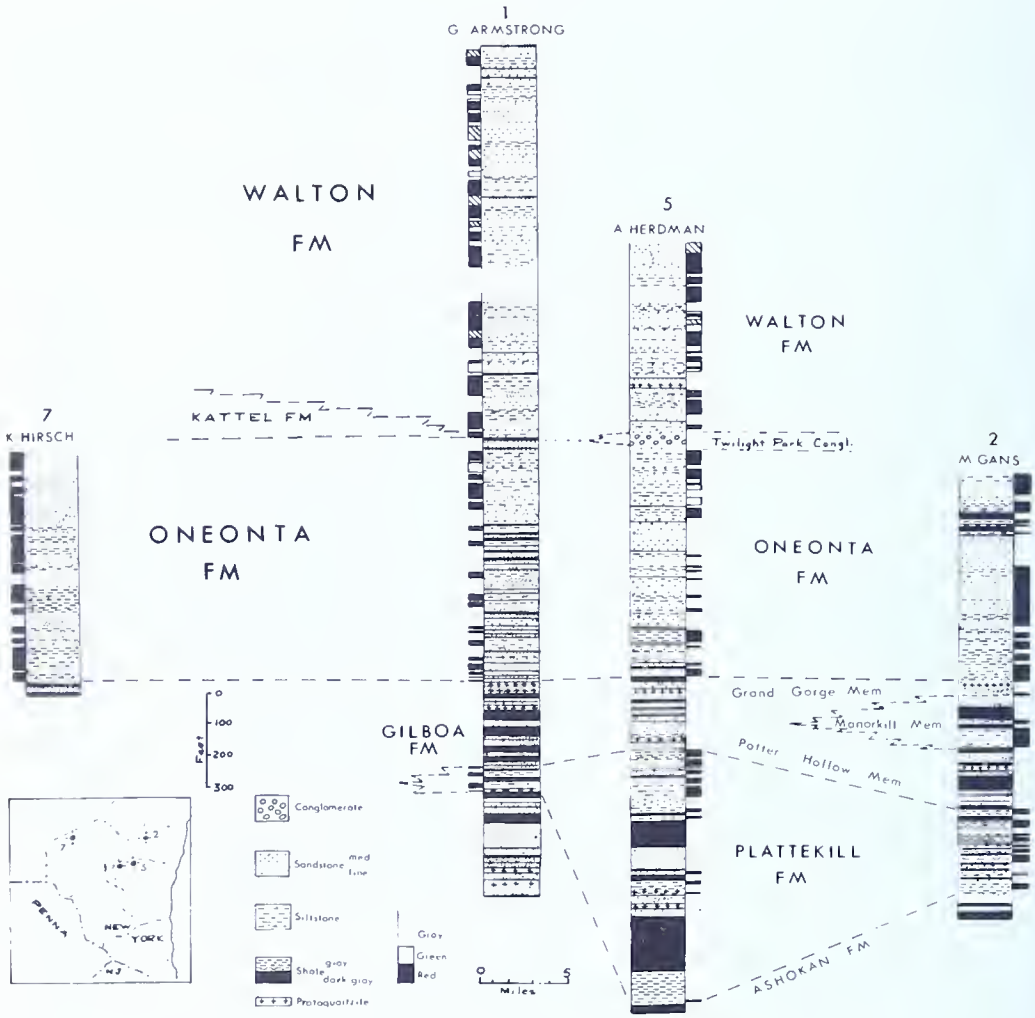

Figure 6. Stratigraphic columns compiled from exploratory gas wells.

but thickens to the southeast. Southwestward from the Schoharie valley the Manorkill thins and wedges out. It is absent in the A. Herdman No. 1 and G. Armstrong No. 1 wells.

Grand Gorge Member

The name "Grand Gorge" is introduced to designate 85 feet of protoquartzite and fossiliferous, medium-dark-gray shales which immediately underlie the red Oneonta Formation in the Schoharie Creek valley. The type section is exposed along Route N. Y. 30 (elevation: 1460 feet), 1.8 miles northeast of Grand Gorge.

The unit has been traced east of the type locality along the Catskill escarpment. It is exposed on Route N. Y. 23 (Durham quadrangle) at an elevation of 1550 feet and is present in the A. Herdman No. 1 and G.

Armstrong No. 1 wells (Fig. 6). South and west of the Margaretville region the distinctive protoquartzite beds of both the Grand Gorge and the Potter Hollow Members wedge out. These beds are found neither in outcrop nor in the wells in the upper Delaware River valley.

Oneonta Formation

Lardner Vanuxem (1840, p. 38) proposed the name "Montrose sandstone or sandstone of Oneonta" for the youngest lithified rock in Otsego, Chenango, Broome and Tioga counties, New York. He described the formation as "...light-colored greenish-gray sandstone, usually hard; fine-grained red sandstone, red shale or slate..." (Vanuxem, 1842, p. 186).

The base of the Oneonta is exposed along Route N. Y. 28 on Franklin Mountain (elevation: 1750 feet), 1.5 miles southwest of Oneonta village. At this locality the formation contains micaceous, pale-red-purple and grayish-red-purple sandstones, siltstones and claystones intercalated with medium-grained, gray, cross-bedded subgraywackes that weather light-greenish-gray. Samples from the K. Hirsch No. 1 well in this same region show that the thickness of the Oneonta is approximately 850 feet.

The Oneonta intertongues with the Cincinattus Formation at Oxford, west of the type locality (Killip, 1961, p. 31). East of Oneonta it occupies a series of low, flat-topped hills immediately north of the West Branch of the Delaware River. The base is exposed in the Schoharie Creek valley along Route N. Y. 30 (elevation: 1600 feet), 1.5 miles northeast of Grand Gorge. The outcrop belt follows the steep Catskill escarpment to Kaaterskill Clove where the Oneonta crops out between 1400 and 2300 feet above sea level. It is exposed along the top of the front southwestward to the Delaware River valley. Northwest of Port Jervis the Oneonta occurs in a sequence of strata assigned by Willard (1936) to the Delaware River flags, a series of supposedly non-red sandstones. A slight thickening occurs between Shohola and Deposit.

Shohola	654 feet
Damascus	766 feet
Long Eddy	685 feet
Deposit	727 feet

The red shales and claystones are less resistant to weathering and erosion than the intercalated gray sandstones and, therefore, form only sparse outcrops. The paucity of exposures led to the belief that only non-red strata are present in the vicinity of Hawks Nest, New York and is the cause of previous misinterpretation of the stratigraphy in the upper Delaware River valley (see: White, 1881; Willard, 1936; Fletcher *in* Broughton and others, 1962).

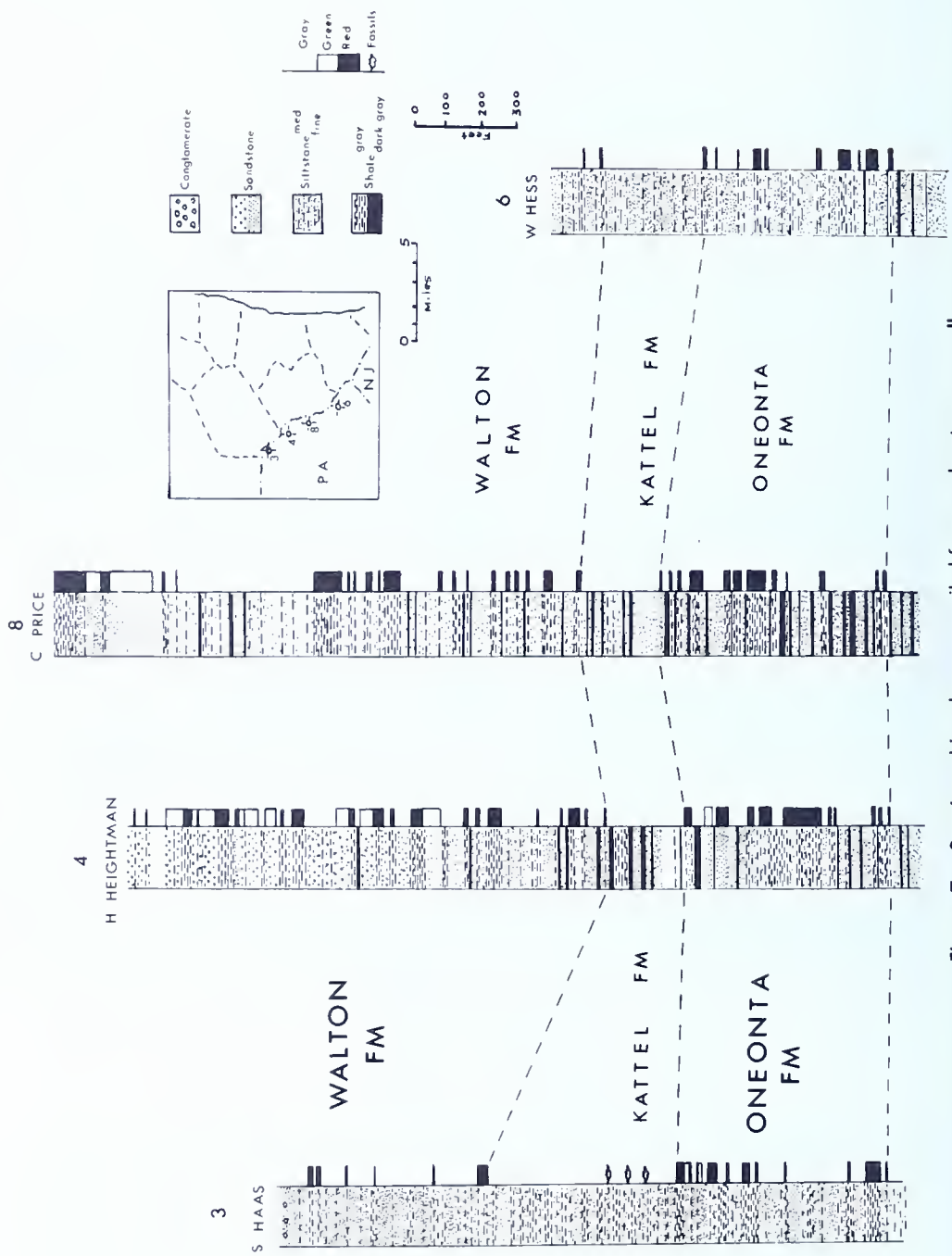

Figure 7. Stratigraphic columns compiled from exploratory gas wells.

Kattel Formation

The fossiliferous Kattel Formation overlies the Oneonta in the western part of the area of investigation. The name "Kattel" was used first by Chadwick (1932, p. 7) for marine shale of lower Enfield age. The Kattel is the eastern equivalent of the Middlesex Formation, for the Sawmill Creek Member of the Middlesex was traced by Sutton into the vicinity of Delhi where it lies above the Oneonta Formation (Sutton and others, 1962, p. 392). Manley (1959) gives the following thicknesses for the Kattel:

Sidney	500 feet
Franklin	400 feet
Delhi	less than 50 feet

In the Margaretville quadrangle the formation has a thickness of only 12 feet. It thins rapidly in the upper Delaware River valley.

Deposit	632 feet
Long Eddy	276 feet
Damascus	287 feet
Shohola	318 feet

The Kattel interfingers with red beds of the thickened Oneonta and Walton Formations east of Delhi, so only thin, gray shales remain. Southwest of Delhi it is found in the S. Haas No. 1, H. Heightman No. 1, C. Price No. 1 and W. Hess No. 1 wells (Fig. 7), but crops out in a quarry along Route N. Y. 97 (elevation: 600 feet), 1.3 miles northeast of Pond Eddy. Its outcrop belt forms a very narrow band northeast of the Delaware River valley and wedges out in the vicinity of Rondout Creek.

Twilight Park Conglomerate

The eastern equivalent of the Kattel is the Twilight Park Conglomerate. Although Chadwick (1944, p. 131–135) correlated the Kattel Shale with the Stony Clove, the Kattel-Twilight Park correlation is supported by the following facts:

1. Thin, medium-dark-gray shales in the Kattel were traced from Delhi to the Catskill Front and were found to lie immediately beneath the Twilight Park.
2. Dark-gray shales are found in the G. Armstrong No. 1 well at the same stratigraphic horizon as the Twilight Park conglomerate in the A. Herdman No. 1 well (Fig. 6).
3. Current structures of the Twilight Park and immediately adjacent strata have the same orientation as current structures in the Kattel. This orientation varies significantly from the red shale tongues (Fig. 3).

4. Nugent (1960) demonstrated that the eastern equivalents of the black shale members of the Rhinestreet Formation are conglomerates.

The Twilight Park Conglomerate is named for excellent exposures at Twilight Park, 0.1 mile south of Haines Falls (Prosser, 1899). The lithology is milky-white quartz-pebble conglomerate with a coarse-grained sand matrix. The unit crops out along the Catskill front at Platte Clove, on North Mountain at Jacob's Ladder, and on Indian Head. It descends westward from 2,000 feet at the type locality to 425 feet in the Phoenicia quadrangle (Fig. 6), then thins and wedges out. It is not present in the G. Armstrong well only nine miles west of the Herdman well and no exposures have been found in the Gilboa and Durham quadrangles.

According to Chadwick (1936, p. 95) the Twilight Park Conglomerate marked the beginning of Upper Devonian sedimentation. New evidence disproves this thesis. The Onondaga Limestone ascends 2,134 feet between the A. Herdman No. 1 well, where it lies at an elevation of 3,923 feet below sea level, and the M. Gans No. 1 well, where it is present 1,789 feet below sea level. In that distance the stratigraphic interval between the Onondaga and the Oneonta thins approximately 500 feet (Fig. 5). Since the base of the Twilight Park lies 425 feet above sea level in the Herdman well; its stratigraphic horizon is located at approximately 2,100 feet in the vicinity of the Gans well (Durham quadrangle). This conglomerate, then, is located about 1,000 feet above the Tully-Geneseo horizon (Gilboa) and therefore, well above the base of the Upper Devonian.

Walton Formation

Chadwick (1933, p. 483) defined as Onteora 1150 feet of red and gray beds which lie between the Twilight Park and the Stony Clove Sandstone in the vicinity of High Peak. The Stony Clove, which Chadwick (1944, p. 130) described as "gray sandstones coarsely flaggy and without a noticeable trace of red color throughout a thickness of eight or nine hundred feet" actually contains three thick zones of red shale and claystone within the type section. Since it is impossible to distinquish the series of rocks formerly included in the Stony Clove Sandstone from the zone of red beds Chadwick reported to be in the basal part of his Katsberg Formation, these two groups of strata are combined with the red beds of Chadwick's Onteora to form a distinctive, mappable unit—the Walton Formation.

The red claystones and shales, which comprise the bulk of the formation, are indistinquishable from those of underlying units. The sandstones, however, are considerably different. In the lower 1200–1500 feet of the Walton the sandstones are medium-grained (modal class: 0.15 mm.), cross-bedded subgraywackes, gray to greenish-gray on fresh sur-

face, but weather to light greenish gray. They contain appreciable amounts of chlorite and exhibit small, reddish-brown spots caused by interstitial iron oxide. The top 200–500 feet contain light-olive-gray, feldspathic sandstones with scattered milky-quartz and yellowish-gray quartzite pebbles. Modal size class of the sand-sized fraction is 1.0 mm., while the pebbles have a modal class of 10 mm. Thin calcareous, shale-pebble conglomerates occur locally.

The type locality of the Walton Formation is Bear Spring Mountain, approximately one mile southeast of Walton. A total of 507 feet are exposed between elevations 1520 and 1900 feet along Route N. Y. 206 on the north side of Bear Spring Mountain. Nowhere is the entire formation exposed, but its maximum thickness is estimated to be 1,800 feet. Strata in the upper 900 feet of the Walton crop out in the Delaware River valley from Deposit to Handsome Eddy and along Route N. Y. 17 from the Neversink River to Deposit. Northeast of the type locality red beds of the unit are exposed above 2,500 feet elevation on Mt. Utsayantha, one mile southeast of Stamford. The Walton interfingers with brownish-gray sandstones and dark-gray shales of the Sonyea and Rhinestreet Formations west of Deposit (Fig. 4).

Wittenberg Formation

The name "Wittenberg" was introduced by Chadwick (1935, p. 140) for the "whitish-looking and pebbly beds" which crop out on the high peaks of the Catskill Mountains. He defined the Wittenberg as the conglomeratic member of the Katsberg Formation and placed it beneath the Slide Mountain Conglomerate of "Chemung" age. Since the Slide Mountain and Wittenberg Conglomerates form one integral lithologic unit with no stratigraphic break between them, all of the strata above the predominantly red and non-conglomeratic Walton Formation are included in Wittenberg. It is the youngest Devonian formation in southeastern New York and is situated only in the central part of the study area along the axis of the syncline.

The lithology of the Wittenberg Formation is cross-bedded, yellowish-gray and, less commonly, purple-red conglomerate. The maximum pebble size is 70 mm. and the sand-sized fraction is composed of milky and rose quartz grains (modal size class: 1.0 mm.). Five types of pebbles are abundant in this conglomerate: milky quartz; dusky-yellow-gray shale, yellowish-gray, medium-grained, micaceous sandstone; pale-yellowish-orange siltstone and red, fine-grained sandstone.

The contact between the Wittenberg and the underlying Walton Formation is transitional throughout an interval of approximately 200 feet. At the type locality, in the Phoenicia quadrangle, this contact is located at an elevation of 2300–2500 feet. An almost continuously exposed section,

1500 feet thick, may be examined on Plateau, Wittenberg, Cornell and Slide Mountains. The upper part of the Wittenberg has been eroded away west of Slide Mountain; at Mongaup Mountain only the basal 100 feet are present.

CONCLUSION

The stratigraphic analysis of the Middle and Upper Devonian non-marine rocks of southeastern New York demonstrates the following features:

1. The regional stratigraphy and tectonics of the basin are better understood when the non-marine and marine facies are treated as a unit.
2. Because of complex facies changes, stratigraphic control can be attained only by close co-ordination of surface and subsurface data.
3. The stratigraphic scheme established by this study provided a basis for definition and correlation of Devonian non-marine units in adjacent parts of the Appalachian basin.

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Subsurface Correlation of Upper Devonian Lithostratigraphy in Northeastern Pennsylvania and Southeastern New York

ABSTRACT

A northeast-southwest trending correlation diagram from Ulster County, New York to Columbia County, Pennsylvania, illustrates significant lithologic features along the outcrop strike of Upper Devonian beds. A generalized sequence from black and gray shales, upward, through shale-siltstone, through siltstone, and finally through sandstone and conglomerate overlies the Onondaga limestone. The section in Ulster County, New York is thinned as a result of wedging out of a shale-siltstone interval and reduction in thickness of the black and gray shales above the Onondaga. The lowest sandstone interval in the northeast part of the area grades into shale and siltstone to the southwest. Generally red shales, siltstones and sandstones occur above the base of the lowermost sandstone interval. A shale unit occurs near the top of the lowest sand interval in the northeast, and continues to the central part of the section, where it disappears.

INTRODUCTION

In the course of an investigation of geologic literature for a mapping project in northeastern Pennsylvania, it was discovered that a number of exploratory wells have been drilled for hydrocarbons in that area and in southeastern New York. The earliest of these was drilled in 1881 and is mentioned by White (1882, 1883). Since then more than fifty exploratory wells have been spudded in this area. Figure 1 shows the locations of these wells and Table 1 gives some pertinent data about them. Through the kind cooperation of George C. Growe, Sr. of the Transcontinental Production Company, sample descriptions of nineteen of these wells were made available for study. With the intention of affecting a correlation of the major post-Onondaga lithostratigraphic units in these wells, a study of strip logs, made from the sample descriptions, was undertaken. Within the framework of this work a detailed correlation of the strip logs is planned.

A section (A-B in Figure 1) was chosen which extends from northern Ulster County, New York, to southern Columbia County, Pennsylvania. It was felt that this section would show significant features along the major outcrop strike of Upper Devonian beds in this region. With the

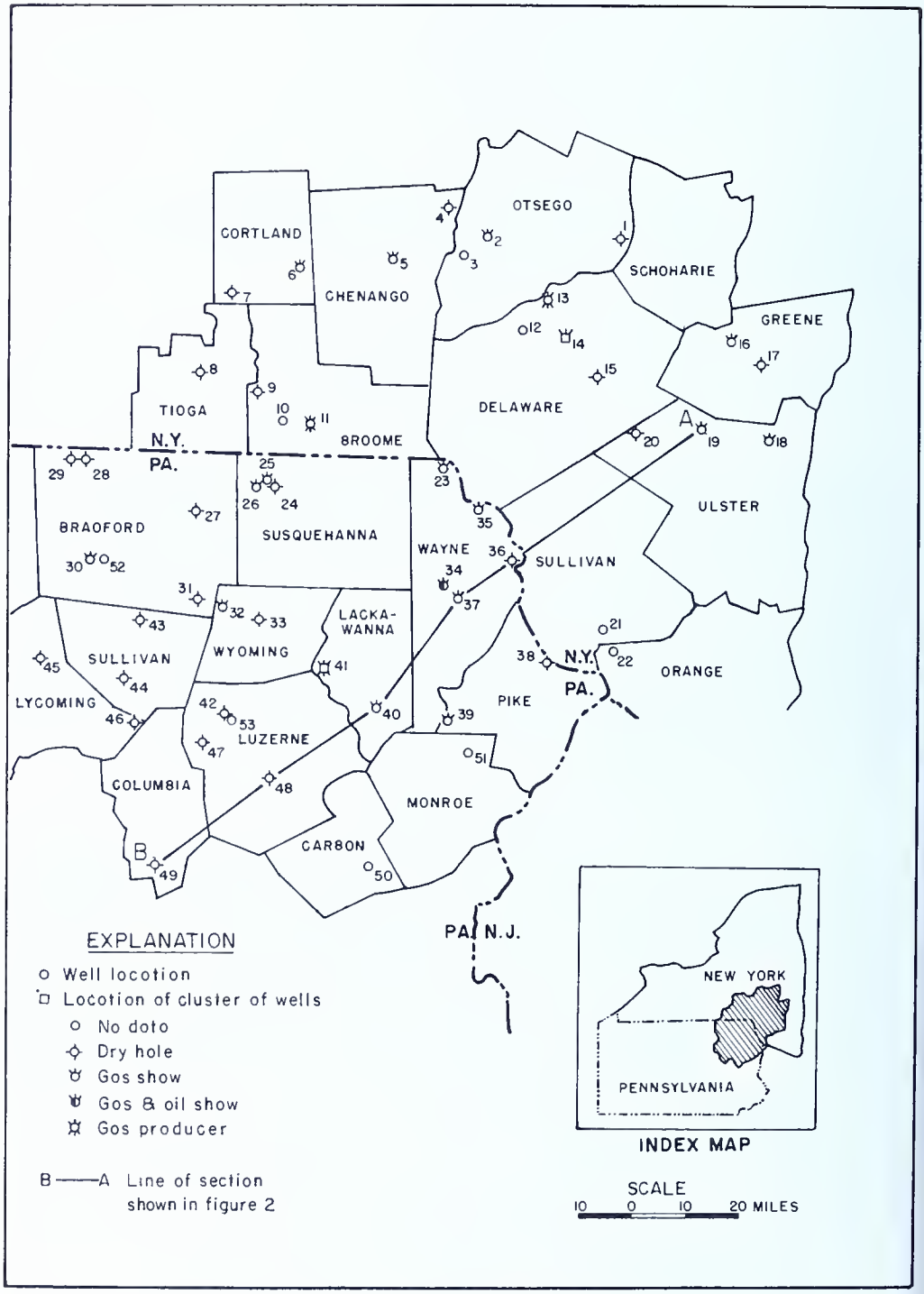

Figure 1. Location Map. N. E. Pennsylvania & S. E. New York showing wells drilled since 1882.

TABLE 1

Index to wells located in Figure 1

	Well Name	Total Depth	Deepest Formation	References and Remarks
1.	P. B. Lum et al	5521'	Precambrian	AAPG, June '62[1]
2.	W. Elliot #1	3689'	Frankfort	AAPG, June '61
3.	Matteson #1	2450'	Oriskany	AAPG, June '53
4.	Lobdell #1	5701'	Precambrian	AAPG, June '50
5.	A well near Norwich	2334'	Marcellus	N.Y.St.M.B. 295, p. 153[2]
6.	A well on Beckwith farm, near Cincinnatus	1800'	?	N.Y.St.M.B. 295, p. 157
7.	Overbaugh #2	3071'	Salina	AAPG, June '53
8.	A well near West Candor	1350'	Hamilton	N.Y.St.M.B. 295, p. 155
9.	Hotchkiss	3850'	Oriskany	AAPG, June '50
10.	Unidentified well at Binghamton	3117'	Hamilton	N.Y.St.M.B. 295, p. 156
11.	A well on Parkhurst Tract, State Hospital grounds	245'	?	N.Y.St.M.B. 295, p. 156 Circa 1890, gas
	A well near Itaska	2000'	?	N.Y.St.M.B. 295, p. 156 Circa 1890, oil
	A well near Chenango Bridge	2000'	?	N.Y.St.M.B. 295, p. 156 Circa 1890, gas (?)
12.	Hazlett #1			Transco Map
13.	K. Hirsch #1	5327'	Frankfort	AAPG, June '62
14.	An area near Delphi where a number of wells were drilled for salt as far back as 1833. In 1931, gas was still emanating from some of them	750'	The deepest	N.Y.St.M.B. 295, p. 158
15.	H. A. Campbell #1	10,993'	Precambrian	AAPG, June '63 O&GJ, Jan. 28, 1963, p. 314[3]
16.	Gaus #1	7185'	Theresa	AAPG, June '59
17.	A well 3½ mi. southwest of Cairo	2200'	?	N.Y.St.M.B. 295, p. 159 Circa 1886
18.	A well at Daly Hotel on north bank of Plaaterskill Creek 3/4 mi. west of Mount Marion Station	120'	Onondaga	N.Y.St.M.B. 295, p. 158, @ 100' gas show
19.	Herdman #1	6400'	Normanskill	AAPG, June '55, '56
20.	Armstrong #1	3810'	Mid Hudson River Shale	
21.	A well in Bushkill Valley where it joins the Neversink at Oakland Valley, in the town of Forestburg	500'	?	N.Y.St.M.B. 295, p. 158
22.	A well in Neversink Valley, 1 mi. south of lower Oakland Valley Bridge	1300'-1400'	"Bluestone"	N.Y.St.M.B. 295, p. 158
23.	Haas #1	5903'	Onondaga	Pa. G. S. (4) M 45[4]
24.	Kelly-Hendrickson #1	?	Onondaga	AAPG, June '58[5]
25.	Kelly-Hendrickson #1A	5874'	Helderberg	AAPG, June '58
26.	E. J. Moran #1	5576'	Helderberg	AAPG, June '60
27.	H. W. Lundy #1			O&GJ, Jan. 28, 1963, p. 314
28.	Anna Carver #1	7220'	Salina	AAPG, June '57
29.	C. U. Teeter #1	4522'	Oriskany	AAPG, June '53
30.	H. French #1	4673'	Oriskany	AAPG, June '55
31.	Blemle #1	12,817'	Tuscarora	O&GJ, Jan. 28, 1963, p. 314 AAPG, June '63
32.	A well at Mahoopenay Creek	2089'	Catskill	Pa. G. S. (2) G 7[6], Circa 1882
33.	J. Sheehan #1	8524'	Oriskany	AAPG, June '54
34.	A well at Dyberry Creek.	2165'	Catskill	Pa. G. S. (2) G 6[7], Circa 1882
35.	H. Heitman #1	4990'	Hamilton	AAPG, June '60
36.	C. Price #1	8740'	Bossardville	AAPG, June '59
37.	Grimm #1	4963'	Hamilton	AAPG, June '60
38.	W. Hess #1	7563'	Helderberg	AAPG, June '59
39.	J. Haag #1	5990'	Hamilton	AAPG, June '60
40.	Schreiber #1	5530'	Delaware River Flags	Transco Map
41.	L. Richards #1	8623'	Helderberg	Pa. G. S. (4) M 45, Discovery well, Harvey Lake Field
42.	Goodwin #1	4730'	Hamilton	AAPG, June '59
43.	B. Bruschart #1	7192'	Oriskany	AAPG, June '56
44.	A. W. Bennett #1	12,343'	Albion	AAPG, June '52
45.	A. E. Ging #1	8118'	Oriskany	AAPG, June '55
46.	Tranor #1	7169'	?	AAPG, June '57
47.	N. J. Harrison #1	5555'	Oriskany	AAPG, June '54

TABLE 1, Continued

Well Name	Total Depth	Deepest Formation	References and Remarks
48. P. Good #1	7583'	Rose Hill	AAPG, June '60
49. P. Kuorr #1	7445'	Tonoloway	AAPG, June '58
50. H. Smith #1	3211'	Onondaga (?)	AAPG, June '63
51. A. M. Price #1			
52. Headley #1			
53. Lopez #1			

[1]Bulletin of the American Association of Petroleum Geologists; Developments in New York State: 1950-1963.
[2]New York State Museum Bulletin, No. 295, 1932.
[3]Oil and Gas Journal, published weekly
[4]Lytle, W. S., et al; A Summary of Oil and Gas Developments in Pennsylvania, 1955 to 1959: Pa. Geol. Surv., 4th Series, Bull. M-45.
[5]Bulletin of the American Association of Petroleum Geologists; Developments in Pennsylvania: 1950-1963.
[6]White, I. C., 1883, The Geology of the Susquehanna River Region in the six Counties of Wyoming, Lackawanna, Luzerne, Columbia, Montour and Northumberland: Pa. Geol. Surv., 2nd. Series, Bull. G-7.
[7]White, I. C., 1882, The Geology of Pike and Monroe Counties: Pa. Geol. Surv., 2nd. Series, Bull. G-6.

exception of Onondaga and Tully, stratigraphic nomenclature is avoided in this paper. Because the emphasis is on correlating major lithologic units, it is feared that the complexities of Upper Devonian stratigraphic nomenclature in Pennsylvania and New York might tend to obscure this aim.

STRATIGRAPHY

Table 2 presents the major lithostratigraphic intervals for the southwest, central, and northeast parts of the area under consideration.

Table 2.

Southwest	*Central*	*Northeast*
	gray and green ss and cgl with gray and red sh and sltst interbeds	gray, green and red ss with red sh interbeds
	red sh with gray, green and red ss interbeds	red sh with gray, green and red ss interbeds
	gray and red ss alternating with red sh and sltst	gray and red ss alternating with red sh and sltst
red and gray sh and gray and green ss	gray ss and gray sh and sltst	gray, some red ss, and gray and red sh and sltst
	gray ss, red sh, gray ss	red sh, gray ss
gray sh and sltst with gray ss and cgl interbeds	gray sltst and sh with some gray ss interbeds	gray sltst and sh with some gray ss interbeds
gray sh with sltst interbeds	gray sh with sltst and minor ss interbeds	gray sh with sltst and minor ss interbeds
gray shale		

Southwest	*Central*	*Northeast*
Tully	*Tully*	
gray sh with some sltst interbeds (gray shale to east)	gray sh with some sltst interbeds	
gray sh	gray sh	gray sh
black sh	black sh	black sh
Onondaga ls	*Onondaga ls*	*Onondaga ls*

In general, each well exhibits an upward transition from black shale to gray shale, to shale-siltstone to siltstone and finally to sandstone and conglomerate. The black and gray shales occupy a much thinner interval in the Herdman well than they do in the wells to the southwest. A shale-siltstone interval that generally overlies the shales is absent in the Herdman well. A gray sandstone overlies the predominant siltstone interval in all but the Good and Knorr wells. It varies from 440 feet thick in the Herdman to 420 feet in the Price, 600 feet in the Grimm and more than 560 feet at the bottom of the Schreiber. In the Grimm and Price wells a shale interval of about 100 feet thick occurs near the top of the unit. In the Herdman well this shale occurs at the very top. In the Good and Knorr wells, where the gray sandstone is absent, 2000 to 2400 feet of gray siltstone and shale occurs, which is lithologically similar to the 1000 to 1500 feet of gray siltstone, underlying the gray sandstone, in the Grimm, Price, and Herdman wells.

The 100 feet of shale that lies at the top of the gray sandstone in the Herdman well, is believed to be continuous with a shale of similar thickness that occurs 120 feet below the top of the gray sandstone in the Price, and 80 feet below the top of the gray sandstone in the Grimm wells. This shale is red in the Herdman and Price wells, and gray in the Grimm. In the Schreiber well a red shale occurs at the top of the gray sandstone, but is not considered to be equivalent to the shale of the eastern wells. W. R. Wagner (personal communication), in the course of a study of Upper Devonian stratigraphy, the results of which appear in this volume, indicated that units above and below the red shale of the Schreiber cannot be correlated with those above and below the 100 feet of shale in the eastern wells. A characteristic gamma ray configuration is also missing from the Schreiber red shale horizon. No shales of this character occur in the Good or Knorr wells.

Above the gray sandstone in the Price and above the red shale in the Herdman is another gray sandstone, which contains some red sandstone, shale and siltstone interbeds. Overlying the gray sandstone in the Schreiber and Grimm wells is about 900 feet of gray sandstone with gray shale and siltstone interbeds. The uppermost interval of red and gray

shale and gray and green sandstone in the Good and Knorr wells is considered to be equivalent to this unit, which in turn is considered to be equivalent to the gray and red sandstone (with red shale and siltstone) of the Herdman and Price wells. Succeeding the gray sandstone (with gray siltstone and shale interbeds) is an interval of gray and red sandstone, alternating with equal amounts of red shale and siltstone. It is 1200 feet thick in the Herdman, 1500 feet in the Price, 970 feet in the Grimm and 800 feet in the Schreiber. A predominant red shale with gray, green and red sandstone interbeds overlies this unit in the Schreiber, Grimm, Price, and Herdman wells. Above the red shale is a gray, red and green sandstone with interbedded red shale at the top of the Herdman well. A gray and green sandstone and conglomerate with gray and red shale and siltstone interbeds overlies the red shale in the Schreiber well. This is overlain by gray and green sandstone and conglomerate with more gray and red siltstone and shale, in turn succeeded by gray, green and red sandstone and conglomerate, interbedded with red and gray shale and siltstone.

In general, it was found that sandstones tend to become more micaceous toward the Schreiber well from both the northeast and southwest.

CONCLUSIONS

Figure 2 represents, in stratigraphic section, a correlation that is the result of this study. Depth to Onondaga, chosen for the datum, is projected in the Schreiber and Grimm wells.

Above the gray and black shales which overlie the Onondaga, the shale-siltstone interval, that occurs between 4900 and 6050 feet in the Price well, is believed to become thinner to the east, and to pinch out before reaching the Herdman well. The gray shale below it is believed to be pinching out too, except that the Herdman intersects it before its zero isopach.

The 450 feet of shale with siltstone interbeds, lying below the Tully horizon in the Knorr well, is presumed to grade into gray shale eastward toward the Good, and to resemble the gray shale it overlies. East of the Good the interval appears to thicken and siltstone interbeds occur in the Price well, between 4900 and 6050 feet.

The gray sandstone, which is found in the Schreiber well and wells to the northeast, and which is absent in the Good and Knorr wells, is believed to disappear southwestward as a result of a lateral gradation to siltstone and shale. Only thin sandstone and conglomerate interbeds represent any trace of this unit here.

The gray sandstone with red and gray shale and siltstone interbeds which overlies the gray sandstone unit in the Herdman and Price wells, is believed to be equivalent to the gray sandstone, shale and siltstone unit in the Schreiber and Grimm wells. It is recognized that the upper unit o

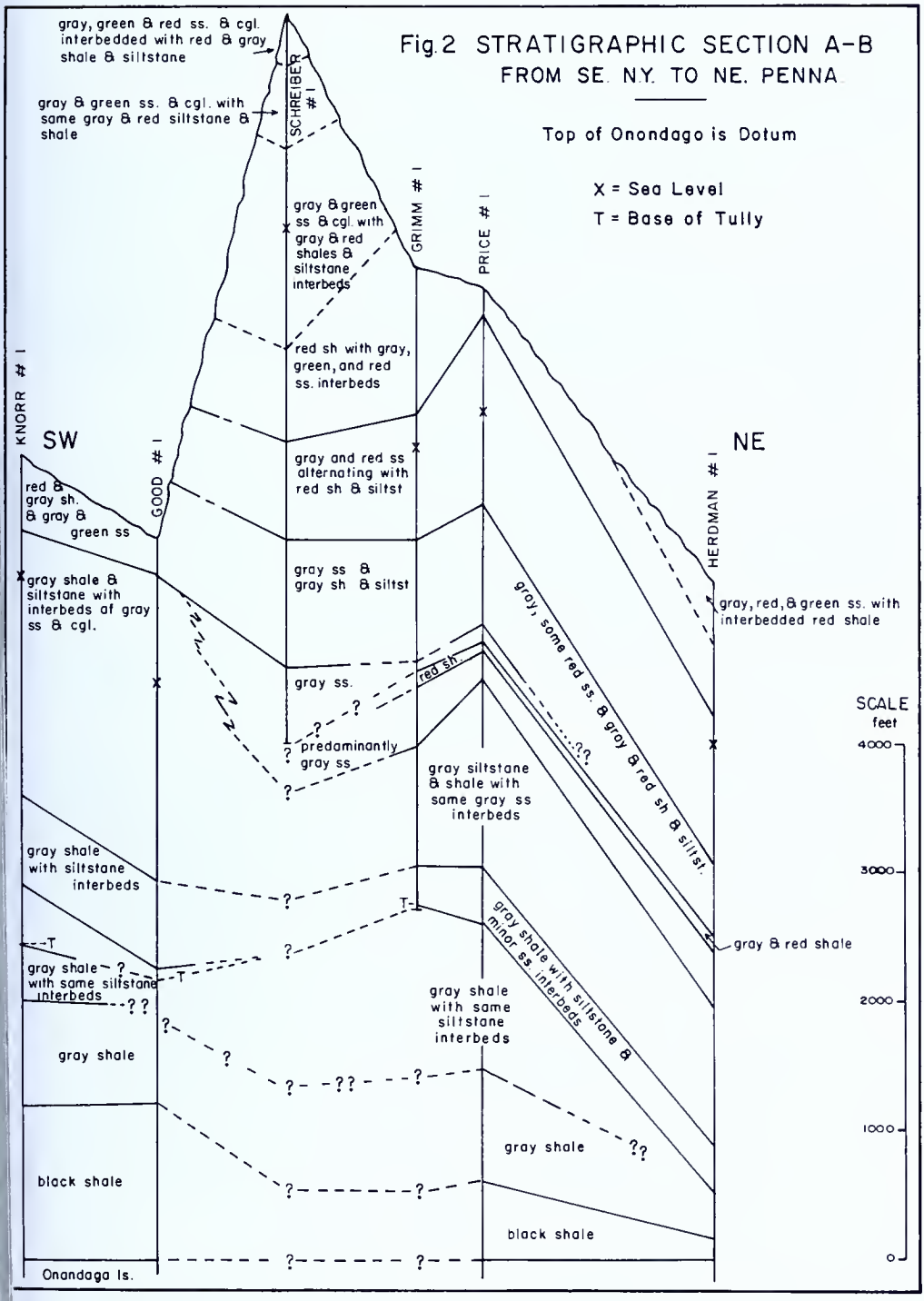
Fig.2 STRATIGRAPHIC SECTION A-B
FROM SE. N.Y. TO NE. PENNA.
Top of Onondago is Datum
X = Sea Level
T = Base of Tully
SW
NE
KNORR # 1
GOOD # 1
SCHREIBER # 1
GRIMM # 1
PRICE # 1
HERDMAN # 1
gray, green & red ss. & cgl. interbedded with red & gray shale & siltstone
gray & green ss. & cgl. with same gray & red siltstone & shale
gray & green ss & cgl. with gray & red shales & siltstone interbeds
red sh with gray, green, and red ss. interbeds
gray and red ss alternating with red sh & siltst
red & gray sh. & gray & green ss
gray ss & gray sh & siltst
gray shale & siltstone with interbeds of gray ss & cgl.
gray ss.
red sh.
predominantly gray ss
gray, some red ss. & gray & red sh & siltst.
gray, red, & green ss. with interbedded red shale
gray siltstone & shale with same gray ss interbeds
gray shale with siltstone interbeds
gray shale with siltstone & minor ss. interbeds
gray & red shale
gray shale with same siltstone interbeds
gray shale
gray shale
black shale
black shale
Onandaga ls.
SCALE feet
4000
3000
2000
1000
0

Figure 2. Stratigraphic section A-B from S.E. N.Y. to N.E. Penna.

the Knorr and Good could be correlated with the gray and red sandstone, (which alternates with red shale and siltstone) of the Schreiber. However, the lack of gray shales in this Schreiber unit indicates that the probable correlation of the uppermost Knorr and Good units is with the gray sandstone, siltstone and shale that overlies the gray sandstone in the Schreiber.

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GLAESER, J. DOUGLAS, Pennsylvania Geological Survey

Catskill Reference Section and its Correlation to Other Measured Surface Sections in Northeast Pennsylvania

ABSTRACT

A reference section of the Catskill Formation at Lehigh Gap in Carbon County between Lehighton and Jim Thorpe, Pennsylvania lies above the Trimmers Rock, and below the Pocono Formation. Fifteen lithologically distinct units designated as informal members occur in the reference section. Correlation of several members with measured sections northeast of the reference section indicates prominent interfingering of sandstones with red siltstones and shales of the lowermost informal member. Although several lithologic units retain persistence among the sections correlated, the distinctive vertical succession of lithic types in addition to lateral continuity of rock properties is important in establishing the correlation.

INTRODUCTION

Initiation of detailed field mapping ($7\frac{1}{2}$-minute scale) by the Pennsylvania Geological Survey in northeastern Pennsylvania was preceded by measurement of surface sections in Carbon and adjacent Monroe Counties (Figure 1). Approximately 70 individual exposures were measured and described in detail with major emphasis upon lithologic properties of every individual unit in each exposure. Detailed descriptions followed the method outlined by Glaeser (1962).

The principal purpose of section measurement was two-fold. First, to determine the precise nature of the lithologic succession of rocks broadly referred to as the Catskill Formation and to define useful lithologic subdivisions. Second, to test the lateral variability in major lithologic subdivisions of the Catskill both for purpose of mapping $7\frac{1}{2}$ quadrangles and correlation on a regional scale.

Reevaluation of Catskill stratigraphy and its subdivisions in northeastern Pennsylvania is required in view of the fact that major units within the Catskill described by White (1881, 1882) and Willard (1939) fail to meet the test of mappability at the scale presently required. In addition, several units at type localities described by both authors are incompletely exposed and apparently do not retain lateral distinctiveness or continuity sufficient to warrant continued nomenclatural usage.

PENNSYLVANIA
Index Map
N.J.
PA.
DELAWARE
RIVER
EAST STROUDSBURG QUAD.
BRODHEADSVILLE QUAD.
LEHIGHTON QUAD.
MONROE COUNTY
WAYNE COUNTY
LUZERNE COUNTY
LACKAWANNA COUNTY
NORTHAMPTON COUNTY
CARBON COUNTY
LEHIGH COUNTY
WILKES-BARRE
Georgetown
Loyd Run
Parsons
Pleasant View Summit
Bear Creek
Cities Summit
Lake Nuangola
Harveys Lake
Pickerel Lake
Porters Lake
Sand Spring Lake
Lake Wallenpaupack
Egypt Meadow
Dingmans Ferry
Minsi Lake
Minsi Pond
Lake Minisink
Sand Spring Lake
Sand Spring Pond
Sand Spring Run
Camp Hemlocks
Bushkill
Shawnee on Delaware
East Stroudsburg
Stroudsburg
Mount Zion
Broad Head
Broad Head Creek
Mount Pocono
Cresco
Pocono Mountain Lake
Pocono Mountain Lake Estates
Pocono Mountain Lake Park
Mountainhome
Pocono Pines
Pocono Manor
Pocono Lake
Pocono Lake Preserve
Pocono Lake Park
Pocono Lake Estates
Pocono Lake Forest
Pocono Summit
Pocono Farms
Pocono Farms Estates
Pocono Farms Village
Pocono Farms Country Club
Pocono Farms Country Club Estates
Pocono Farms Country Club Estates Lake
Pocono Farms Country Club Estates Lake Park
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The writer wishes to acknowledge Michael Forth who assisted during the summer of 1962 in the task of section measurement and description. W. R. Wagner and J. F. Wietrzychowski have contributed in discussions concerning the Catskill and its subsurface expression.

CATSKILL FORMATION REFERENCE SECTION AT LEHIGH GAP

The term "Catskill" is used in this paper despite ambiguities which exist between the chrono- and litho-stratigraphic correlations with the Catskill of New York. The term "Catskill" is well established in the geologic literature and is useful in conveying, at least in a general sense, a classic interval known to all North American stratigraphers.

Catskill Formation as described herein has several distinctive lithologic subdivisions. These subdivisions are currently under examination with regard to their mappability. As such work progresses, undoubtedly several mappable subdivisions can be designated formations, resulting in the elevation of the term "Catskill" to group status. Although the change in rank is anticipated, such change is not proposed in this paper. Herein, the Catskill Formation is used to designate all rocks stratigraphically beneath the Pocono Formation and above the Trimmers Rock. Member subdivisions within the Catskill Formation are designated by letters to connote informal usage.

The most completely exposed succession of Catskill and related strata in the region under consideration is found in the nearly continuous sequence of exposures extending from the north edge of Jamestown northward to the south edge of Jim Thorpe (formerly Mauch Chunk) along U. S. Route 209 and along the tracks of the Central Railroad of New Jersey on the west bank of the Lehigh River (Figure 2). Rocks in these cuts dip very steeply to the northwest (slightly overturned at places) and strike at nearly right angles to the traverse direction so that this imposing group of easily accessible exposures occurs within a very limited geographic interval. The stratigraphic position of the Lehigh Gap exposures can be readily defined by two conspicuous marker horizons, (1) the Tully-Burket, a 30-foot dark-gray (N-3) fine siltstone-shale with a 10-20-foot abundantly fossiliferous zone (Tully) at its base or midsection exposed on the east bank of the Lehigh River east of Jamestown, and (2) the Pocono Formation, ridge-forming clastics exposed at the tight U-shaped bend in the Lehigh River just south of Jim Thorpe (Figure 2).

Sub-Catskill Units

Two distinctive rock units are identified below the Catskill Formation in the Lehigh Gap (measured sections VI A and VI B, Figures 2 and 3). The lower unit is the Brallier, a monotonous gray, gray-green sequence of alternating shales, siltstones, and coarse siltstones. There is a distinctive

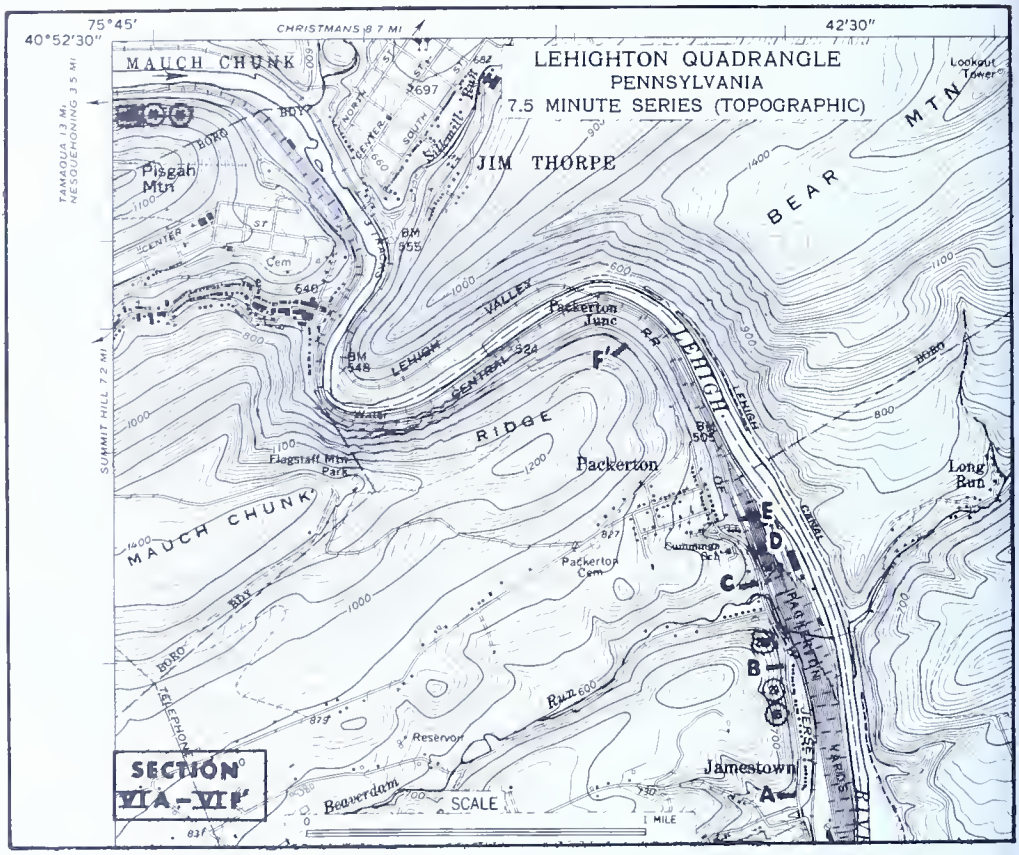


Figure 2.—Locations of meosured sections of Lehigh Gop. Sections VI-C, VI-D, VI-E, ond VI-F' represent Cotskill reference section.

increase in the amount of coarse siltstones in the upper portion of the unit. The upper 409 feet were measured and are shown in Figure 3. The base is not exposed along U. S. Route 209 and the projected position of the Tully as measured on the east bank of the Lehigh River is approximately 200 feet below the lowest measured Brallier unit in Figure 3.

Above the Brallier is the Trimmers Rock which in this section has a distinctive three-fold lithologic subdivision. A lower alternating sandstone, siltstone, and shale succession is overlain by about 300 feet of red (National Research Council Color Chart designations 5R and 10R) and green interbedded shales and siltstones. Only the upper third of this middle Trimmers Rock interval is exposed (Figure 3). The topmost Trimmers Rock unit contains massive very fine-grained sandstones, abundant siltstone and minor shale none of which is red (olive and green to greenish gray predominate). This upper portion is characterized by flow roll sedimentary structures. Frakes (this volume) has described the Trimmers Rock in detail.

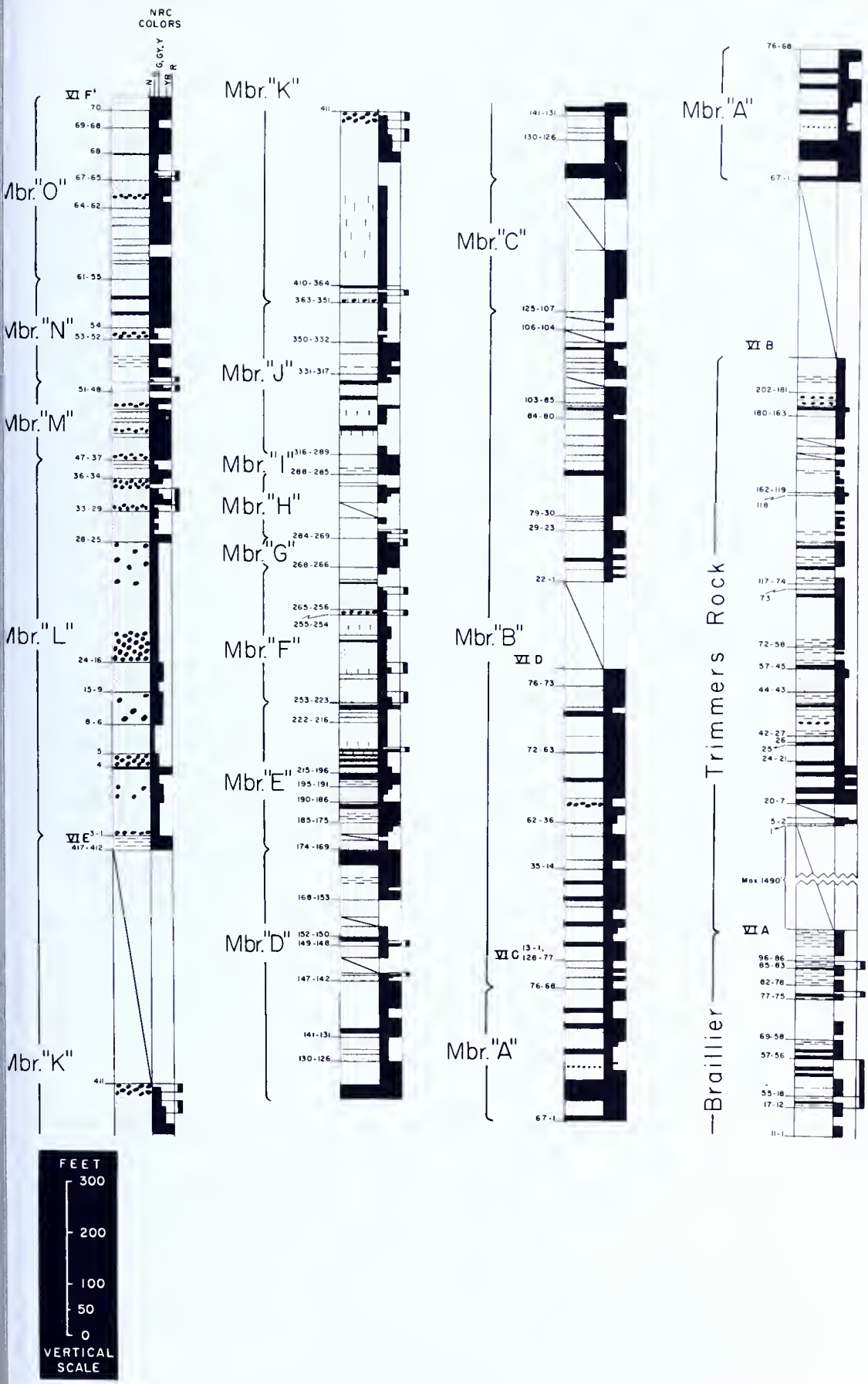


Figure 3.—Catskill reference section (VI-F' through VI-C) and the Trimmers Rock-Braillier interval, (VI-B and VI-A). See legend on Figure 6.

Catskill Formation Subdivisions

Fifteen major lithologically distinctive units within the Catskill are shown in Figure 3 and designated member "A" (base) through member "O" (top). Total thickness of the Catskill at this reference section is 5,687 feet. Individual bed-unit numbers are listed on the graphic summary of the Lehigh Gap Catskill reference section (Figure 3) to indicate the number of discrete lithic units which constitute each of the informally designated members. Each of the 15 informal members of the Catskill Formation at Lehigh Gap portrayed in Figure 3 is described in Table 1.

Lowermost members "A" and "B" (Table 1) are dominated by red color and fine-grained lithology. Their differences lie in the fact that sandstone is lacking in member "A" whereas member "B" is bounded, at its base and top, by distinctive sandstone units. Several sandstone beds also are intercalated with the dominating red siltstones and shale lithology of member "B".

The major sequence of prominent sandstones occurs in members "F" through "K" interrupted only by two thin red siltstone units (members "G" and "I"). The first principal conglomerate bodies occur in members "L" and "M", the upper member "M" being distinguished by the fact that it is the only principal red conglomerate in the Catskill Formation at the Lehigh Gap reference section. The two succeeding members, "N" and "O", are distinct in their fine-grained character (which contrasts with the underlying conglomerates of members "L" and "M") and the identifying red coloration of sandstones in member "O". Several feet of red siltstones occur just above this topmost Catskill member (not shown in Figure 3) and are interbedded with lowermost buff sandstones of the overlying Pocono Formation.

Table 1. *Description of informal members of the Catskill Formation at the Lehigh Gap reference section*

Informal member	Section & inclusive unit no.	Thickness in feet	Lithic properties
"O"	VI-F'70-55	355	Ss, dominantly red. Approx. ⅓ slts. mainly red, gray, and gray green. 6-ft. cgl. in midportion.
"N"	VI-F'54-48	190	Basal slts. with red and green color mixture. Topmost unit red slts. Dominant lithology is slts., a cgl. and Ss. in midportion. Two red shales in upper ⅓, and one green coarse slts. in lower ⅓.
"M"	VI-F'47-37	196	Three red conglomerates, red ss., and minor red slts. Topmost red Ss grades upward into gray Ss.
"L"	VI-F'36-1	734	Prominent Ss. and cgl. sequence. Thick cgl. in middle, two in lower ⅓ (one marking base) and two near top. Also three

Table 1. (Continued)

Informal member	Section & inclusive unit no.	Thickness in feet	Lithic properties
			major conglomeratic Ss. In lower ¼ one thin red shale and an underlying red Ss. Blue-gray Ss. marks top.
			(members "O" through "L" measured along U.S. Route 209)
"K"	VI-E 417-351	863	Dominantly Ss. (gray and gray-green). Ss. calcareous in lower ½. Calcareous cgl. at base and red coarse slts. caps the member. Top ½ nearly all covered.
"J"	VI-E 350-289	301	Ss., calcareous in lower ¼. Three gray shales in lower ½, lowermost one calcareous. Upper ½ is Ss. and one prominent red slts.
"I"	VI-E 288-285	35	Red slts. and coarse slts.
"H"	VI-E 284-269	121	Ss. and minor slts. Midportion covered.
"G"	VI-E 268-266	56	Red slts., color mixture of red and green in top few feet.
"F"	VI-E 265-223	261	Dominantly Ss., calcareous in part. Cgl. in middle. No red beds present.
"E"	VI-E 222-169	284	Basal Ss., top unit shale and slts. Prominent Ss with shale. Upper Ss. calcareous in part. Multiple colors with green dominant in Ss.; red, in finer grained lithologies.
"D"	VI-E 168-116	466	Basal and topmost units are prominent red shales. Between are Ss. and slts. with two thin shales. Lower and upper ⅓ dominantly red. In upper ⅓ is 1st gray (N6) Ss., (VI-E 152) above base of Catskill.
"C"	VI-E 115-107	281	Slts., all red except green unit at base. Middle part covered.
"B"	VI-E 106-1, VI-D 76-1, VI-C 128-68	1,283	First olive (Y) ss. above Catskill base marks base of member "B"; green Ss. occurs at top. Slts., dominantly red, is prominent lithology. Interbeds of Ss. are generally green and olive. Numerous shale interbeds (most are red), each up to 10 feet thick.
			(members K through B (VI-D 1) measured along Central of New Jersey railroad tracks, west bank of Lehigh River)
"A"	VI-C 67-1	261	Prominent red alternating slts. and shale. Some units green and olive. One 1"-2" conglomerate contains shale and quartz fragments up to 4 mm. Member "A" contains no sandstone.
	BASE OF CATSKILL FM.—TOTAL THICKNESS 5,687 feet		
	VI-B 202-1, VI-A 96	2,381.2	Trimmers Rock
	VI-A 95-1	409.6	Brallier
	(Sections VI C-128 through VI A-1 measured along U. S. Route 209)		

CORRELATION

Tentative correlations of Catskill members at Lehigh Gap with two other sets of measured sections to the northeast parallel to regional strike

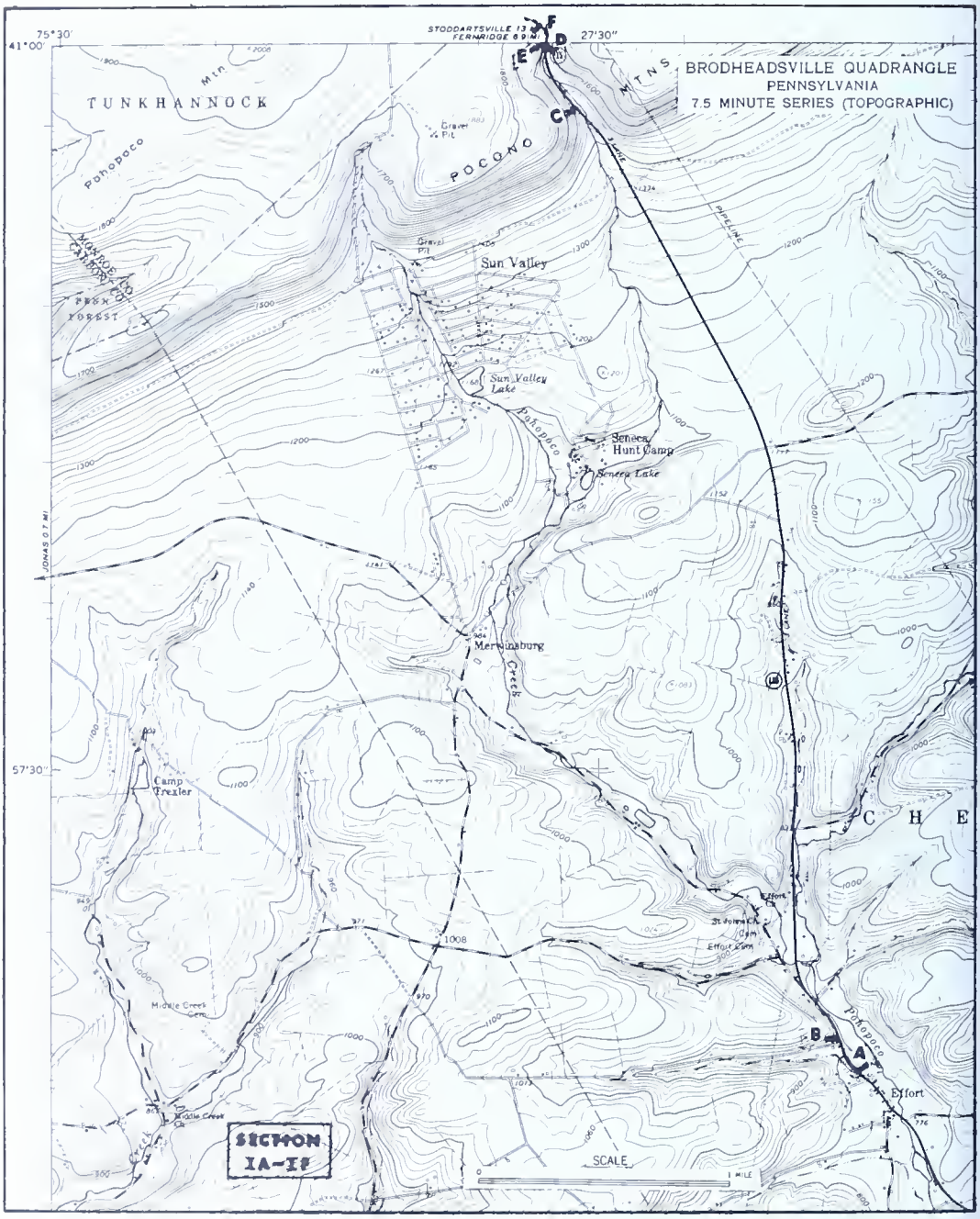


Figure 4.—Locations of measured sections I-A through I-F at Effort and to north along Route 115. Figure 1 indicates location of this area with reference to Lehigh Gap.

are shown in Figure 6. The section closest to Lehigh Gap begins at Effort, Pennsylvania (Figure 4). Figure 5 indicates the locations of the 18 principal parts of the third and northeasternmost section the base of which

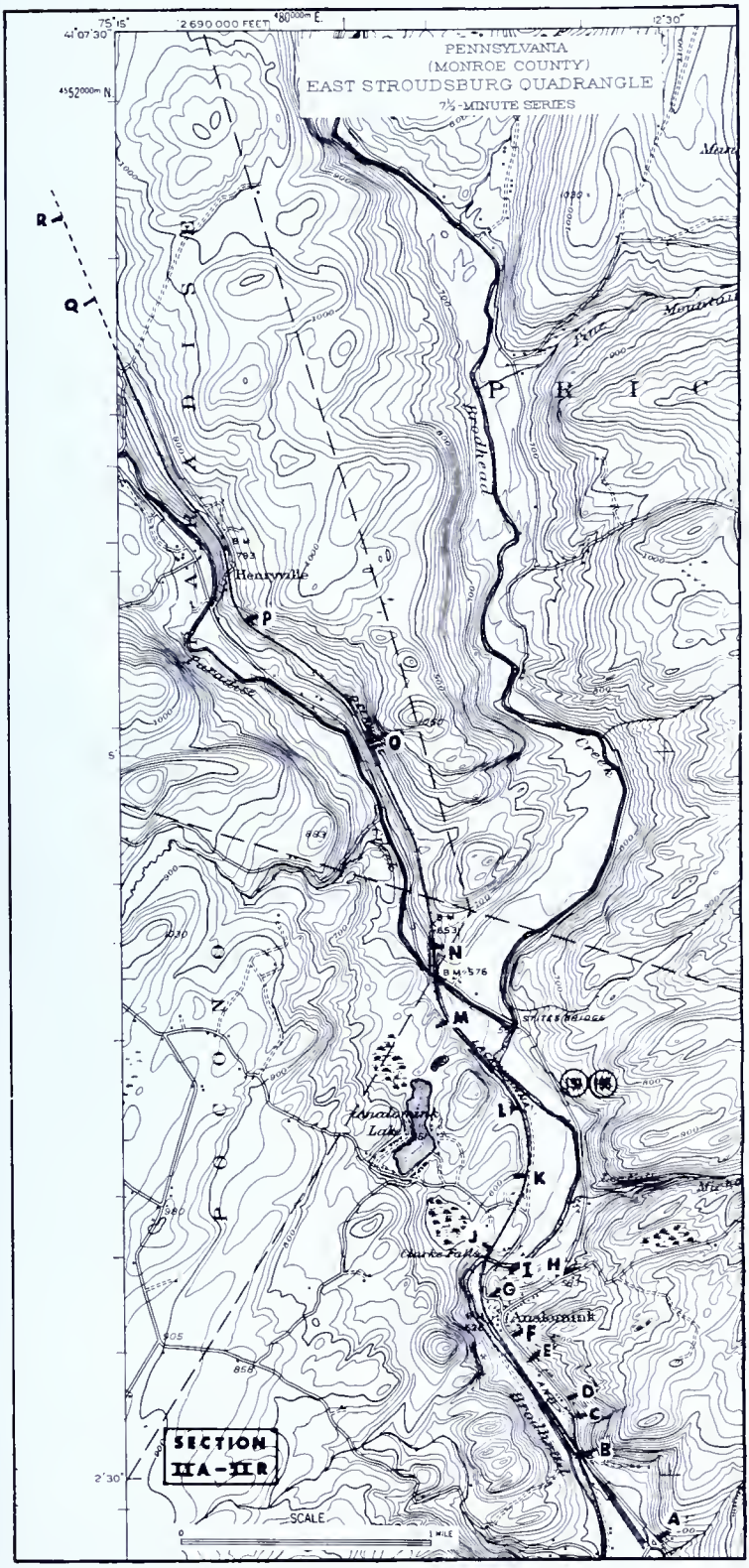


Figure 5.—Locations of measured sections II-A to II-R along Route 191-196 and railroad. Sections II-H and II-I are on strike with II-G and are not shown on the stratigraphic correlation diagram (Figure 6). Figure 1 indicates relationship between this area and Lehigh Gap.

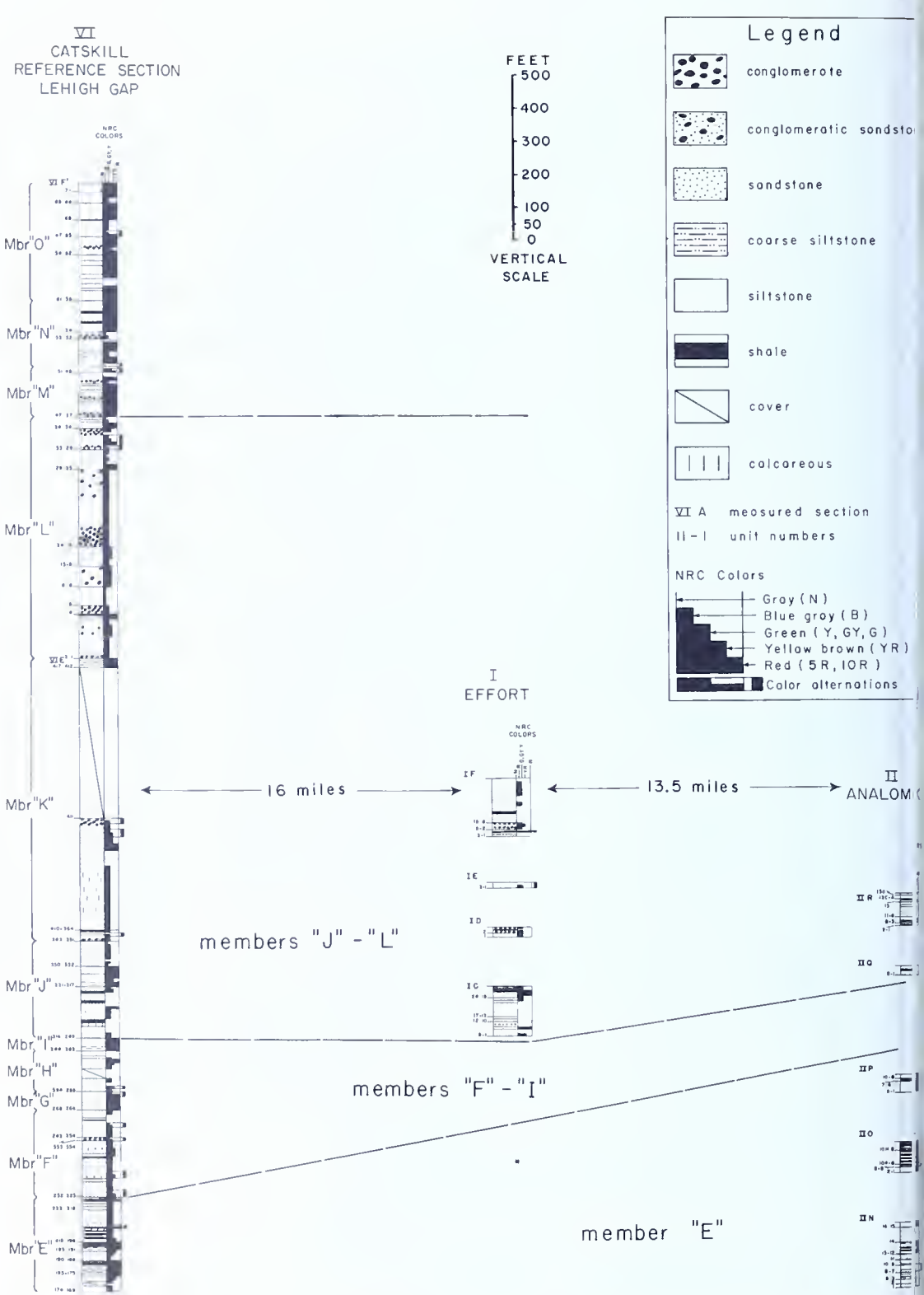
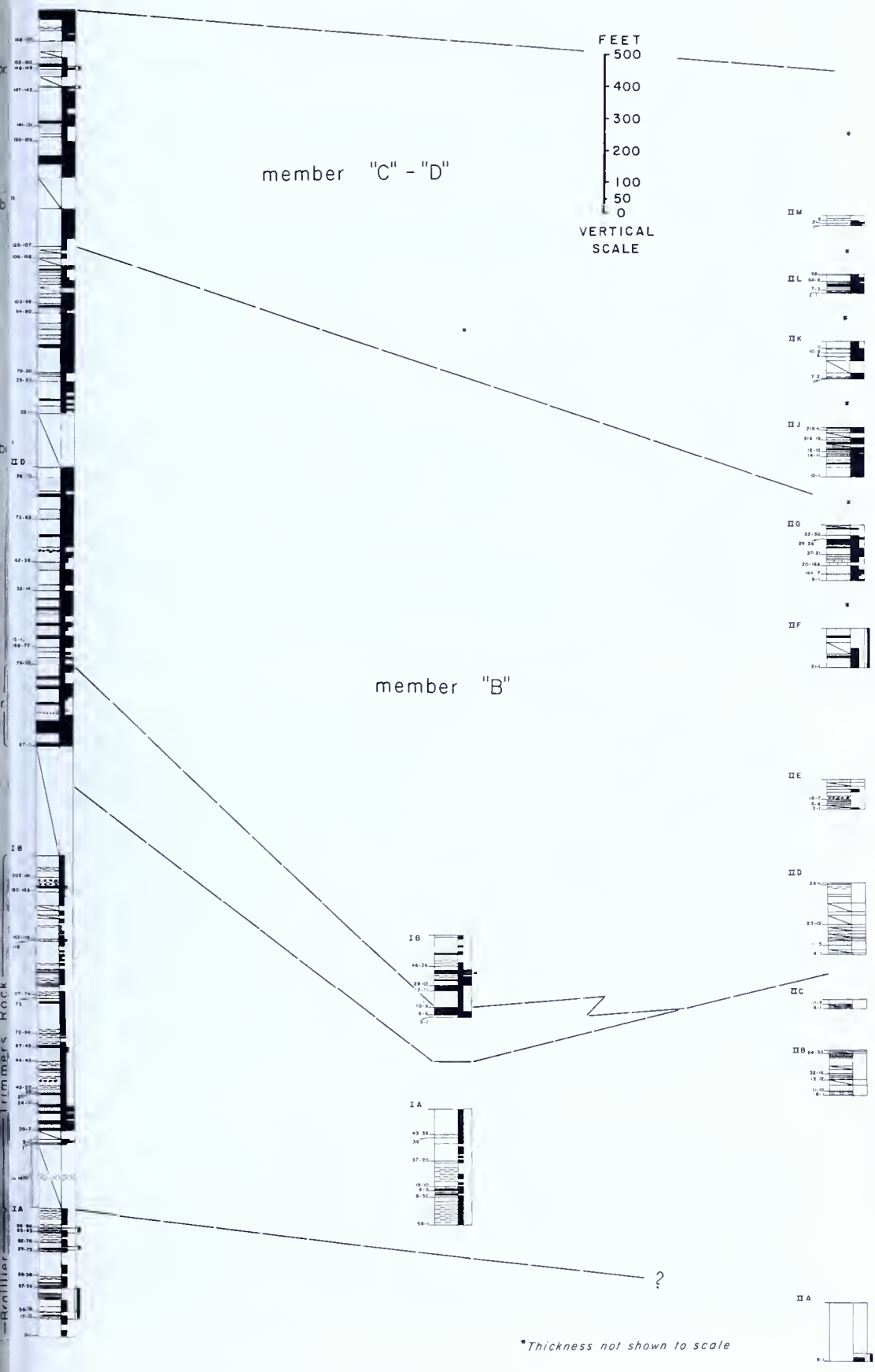


Figure 6.—Stratigraphic correlatian diagram af Catskill Farmatian reference sectian ta measured sectians near Effart (Fig. 4) and Analamink (Fig. 5). Upper half af sectian shawn an this page; lawer half shawn an next page.

V (lower part)

I (lower part)

II (lower part)



*Thickness not shown to scale

(TULLY - BURKET DATUM)

is exposed just south of Analomink in the East Stroudsburg 7½-minute quadrangle.

In deriving the correlations of the three sections shown in Figure 6, vertical lithologic succession is of prime importance and outranks lateral persistence in lithologic character (viz., color, grain size) as a correlation guide. The following are some of the important features indicated by the general correlation shown in Figure 6.

1. Member "A", characterized by lack of sandstones, is of minor significance at Effort (Section I) and is lacking altogether at Analomink (Section II). Evidently, major sandstones are intertonguing with this red siltstone and shale body along the northeast-southwest trend of the outcrop belt.
2. At Analomink, sections II L and II M contain the first gray sandstones above the Catskill base, a feature, in addition to lithologic succession, which serves to support correlation of these two exposures with the lower portion of member "D" at Lehigh Gap.
3. Sections II Q and II R north of Analomink lie above a red siltstone and shale succession and are dominated by sandstone. This supports the correlation between these prominent sandstone units north of Analomink with member "J" at the Catskill Formation reference section.

SUMMARY

Fifteen informal members are designated within the Catskill Formation reference section at Lehigh Gap on the basis of lithologically distinctive properties. The Catskill Formation at its reference section is bounded at top and base by prominent red-bed horizons. Tentative correlations of rocks exposed to the northeast in the Analomink and Effort areas with informal Catskill members at Lehigh Gap suggest that vertical variation in the Catskill succession is a critical correlation tool. Significant changes in lithic character laterally along the outcrop belt are notable in the three stratigraphic sections particularly in basal Catskill beds. Nonetheless, distinctive lithologic units, such as the first gray sandstone above the Catskill base, appear to persist along strike for a considerable distance. Confirmation of the validity of the correlations proposed and usefulness of the members described awaits completion of mapping in this region.

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WALTER R. WAGNER, *Pennsylvania Geological Survey*

Correlation of Susquehanna Group in Part of Northeastern Pennsylvania

ABSTRACT

The Susquehanna Group from Bradford County to Pike County, Pennsylvania is divided on the basis of rock type, color, and gamma ray-neutron log character. The lithology is composed of seven major rock units which in order from oldest to yougest are: dark shale, siltstone, lower sandstone, shale-siltstone, lower sandstone-shale, upper sandstone, and upper sandstone-shale. The group is subdivided by color into a lower, middle, and upper red unit. Both rock and color units are related to gamma ray-neutron correlations which are considered to be approximately parallel to lines of contemporaneity.

The rock and color units are fitted into the stratigraphic nomenclature proposed by White (1881, 1882) and Willard (1935, 1939) and correlations are carried from subsurface into outcrop sections in the Ransom quadrangle, Lackawanna County and at Lehigh Gap, Carbon County.

INTRODUCTION

Since the middle 1950's more than a dozen wells have been drilled in northeastern Pennsylvania through the Upper Devonian sequence. The release to the public of the sample cuttings and radioactivity logs from these wells has made possible a study of the regional relations within the sequence.

This paper correlates five of the wells in a cross section from Bradford County east to Pike County, Pennsylvania (solid line, Figure 1). A tentative correlation is also attempted from subsurface into outcrop sections in the Ransom quadrangle, Lackawanna County and at Lehigh Gap, Carbon County (dotted line, Figure 1).

The stratigraphic names proposed by White (1881, 1882) and Willard (1935, 1939) illustrate one way in which the Upper Devonian strata can be subdivided.

The locations and data of the wells used in the cross sections are as follows:

Charles Blemle No. 1, Pure Oil Co., Wilmot Twp., Bradford Co., Monroeton quad. 740 ft. south of 41°35′ and 7700 ft. east of 76° 20′, T.D. 12,843 ft.

Lawrence Richards No. 1, Transcontinental Production Co., Ransom Twp., Lackawanna Co., Pittston quad., 1800 ft. south of 41° 25′ and 2500 ft. east of 75° 50′, T.D.8623 ft.

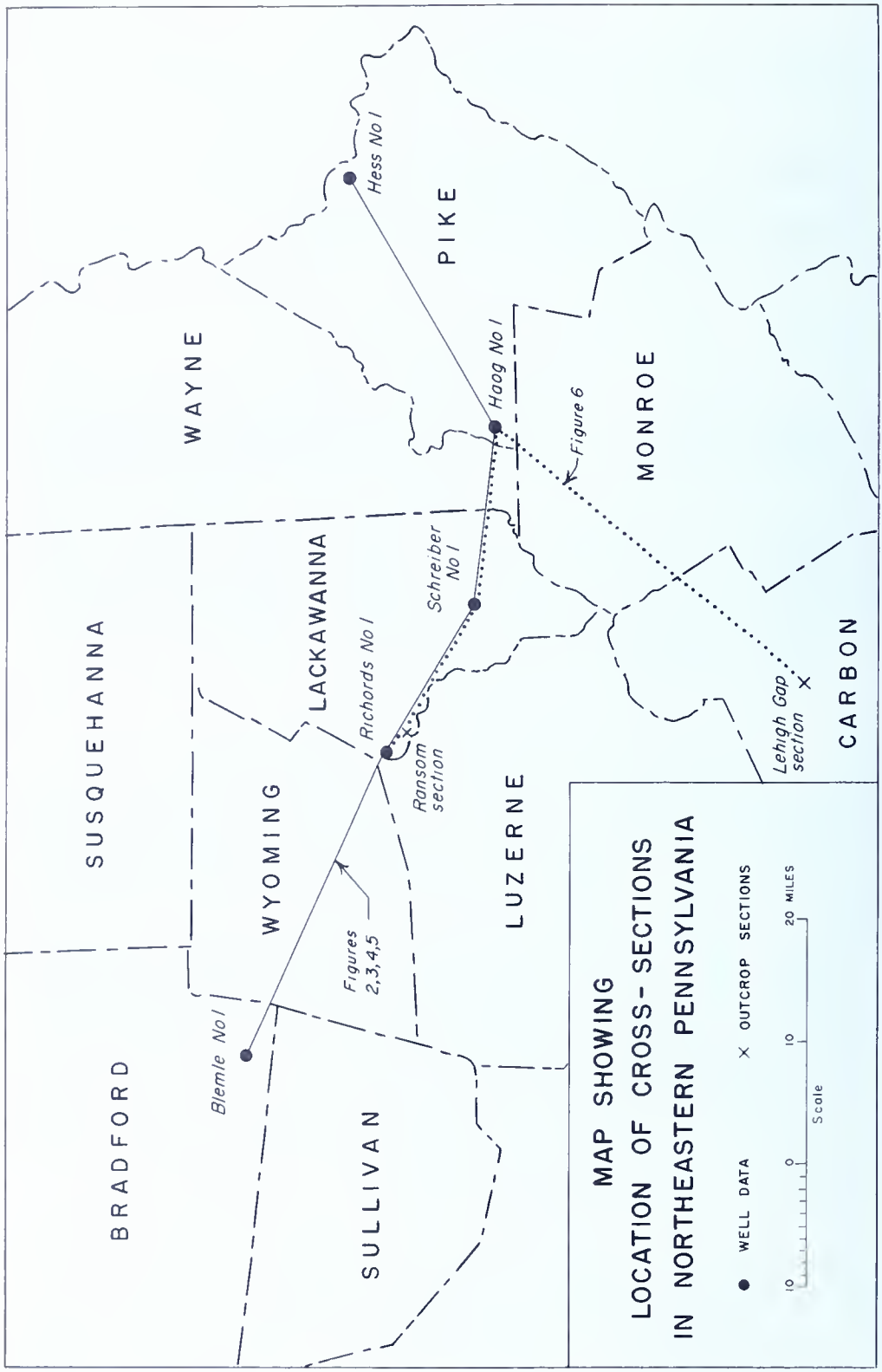


Figure 1. Map showing location of cross-sections in Northeastern Pennsylvania

George Schreiber No. 1, Transcontinental Production Co., Spring Brook Twp., Lackawanna Co., Scranton quad., 10,200 ft. south 41° 20′ and 4100 ft. west of 75° 35′, T.D.5530 ft.

Jennie Haag No. 1, Transcontinental Production Co., Greene Twp., Pike Co., Ariel quad., 11,100 ft. north of 41° 15′ and 3,200 ft. east of 75° 20′, T.D.5990 ft.

Walter Hess No. 1, Transcontinental Production Co., Shohola Twp., Pike Co., Milford quad., 11,250 ft. north of 41° 25′ and 2000 ft. west of 74° 55′, T.D.7563 ft.

The well samples were washed, immersed in water, and examined with a magnification of approximately six times. To show detail or when the chips were small a magnification of 18 was used. Color was determined from the Rock Chart distributed by the Geological Society of America. After examination the data were plotted on strip logs of scale of one inch to 100 feet and related to the radioactivity logs.

The writer thanks Transcontinental Production Company and Pure Oil Company for releasing the well information and he wishes to express his appreciation to J. Douglas Glaeser who guided him through the Lehigh Gap and other sections along the Pocono escarpment and to Thomas M. Kehn who gave so freely of his ideas and outcrop descriptions in the Ransom quadrangle.

STRATIGRAPHY OF THE SUSQUEHANNA GROUP

The name Susquehanna Group was suggested by Miller and Conlin (1961) as a rock-stratigraphic term to apply to the whole Upper Devonian sequence from the top of the Hamilton Group upward "to the top of the youngest, locally mappable red bed." In this paper the term is used in the same sense.

Figure 3 is a cross section from Bradford County to Pike County showing the relationship among rock type, color, and radioactivity correlation. The column representing each well is divided in half, the left part showing major rock type and the right side indicating color. Two kinds of correlation lines are shown connecting the columnar sections. The irregular lines connect units of lithologic similarity only, with no intention of showing units bounded by lines of contemporaneity. The straight, numbered lines are correlations based on the similarity of character of the gamma ray-neutron logs. It is suspected that these radioactivity correlations may approximately parallel time lines.

Whereas the lithologic relationship to the gamma ray-neutron correlations is emphasized in Figure 3, color relationship to the radio-activity correlation is shown in Figure 4. The uneven lines mark the boundary between different colors and the straight, numbered lines again indicate the radioactivity correlations.

Tully Formation And Adjacent Lithologies (Figure 2)

Figure 2 shows the lithology within and adjacent to the Tully Formation in four of the five wells under discussion. A percentage columnar section is plotted between the gamma ray log and neutron log of each well.

The 110 feet of limestone in the Blemle well is called Tully because its thickness and stratigraphic position are similar to the thickness and position of the limestone called Tully in the Oriskany gas fields in Clearfield and Cameron Counties, Pennsylvania. It is only assumed that this limestone is inpart stratally continuous with the 10± feet of Tully Limestone near Tully, New York.

The Tully thins from 110 feet in the Blemle well to a trace of limestone in the Richards well. East of the Richards it disappears and its position is occupied by dark-gray, non-calcareous shale. The stratigraphic position of the Tully where limestone is not present can be seen in the configuration of the gamma ray log. The dark shales which replace the Tully in the Haag and Hess wells have a lower level of radioactivity than similar shales above and below. In like manner the Tully in the Blemle well also has a lower gamma ray intensity than adjacent shales.

The datum plane of the cross sections (Figure 2, 3, and 4) is the top of the Tully limestone in the Blemle well and on its stratigraphic position to the east where the Tully position is estimated from the radio-activity log.

If gamma ray-neutron logs are lacking, the position of the Tully, where it is absent, can be approximated by correlation of lithologic markers above and below the Tully. About 300 feet above the Tully in the Richards and Haag wells and 340 feet in the Hess well is the base of a black (N2-1) shale zone. The base of this black shale is the uppermost radioactivity correlation line in Figure 2. A limestone or calcareous, fossiliferous shale, which changes eastward into a slightly calcareous siltstone, is found 260 feet below the Tully top in the Blemle well to 310 feet underneath the estimated position of the Tully equivalent in the Hess well. Black shales are present just above and below this horizon in the three eastern wells. This horizon, the lowest gamma ray-neutron correlation line in Figure 2, has a distinctive radioactivity character and represents a change from shales downward into silty shales or siltstones. The top of this siltiness appears to be a good place to put the boundary between the Susquehanna Group and the Mahantango Formation of the Hamilton Group.

The base of the Rhinestreet black shale in western New York has been considered a time-stratigraphic marker by Sutton (1960, p. 11) and the New York Survey has used the dark shales to subdivide the Upper Devonian into time-stratigraphic units (Fisher and others, 1961). Assuming that the dark shales are approximately time-parallel, it is likely that the gamma ray markers above and below the position of the Tully in the wells

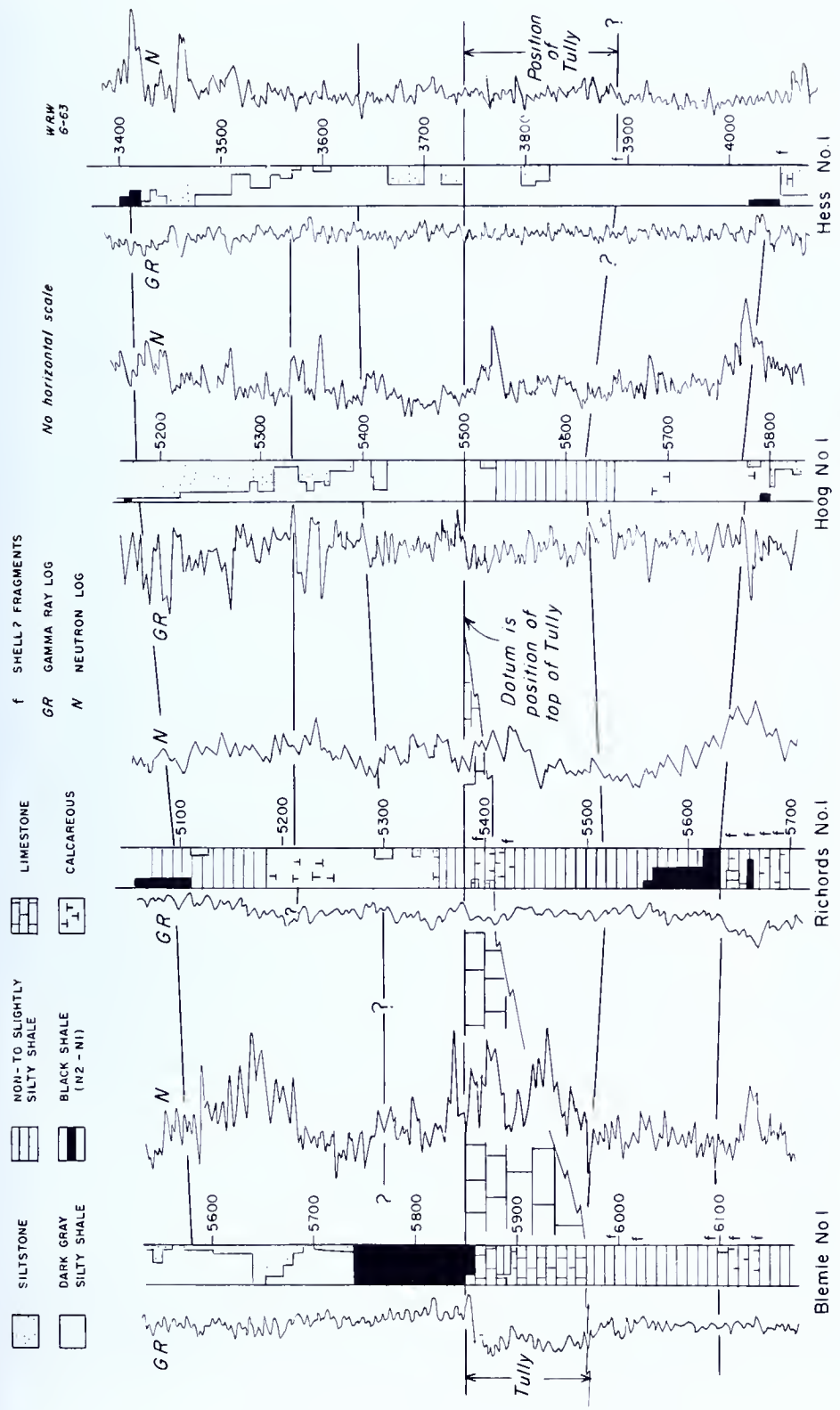


Figure 2. Radioactivity and Lithologic Correlation of Tully Limestone.

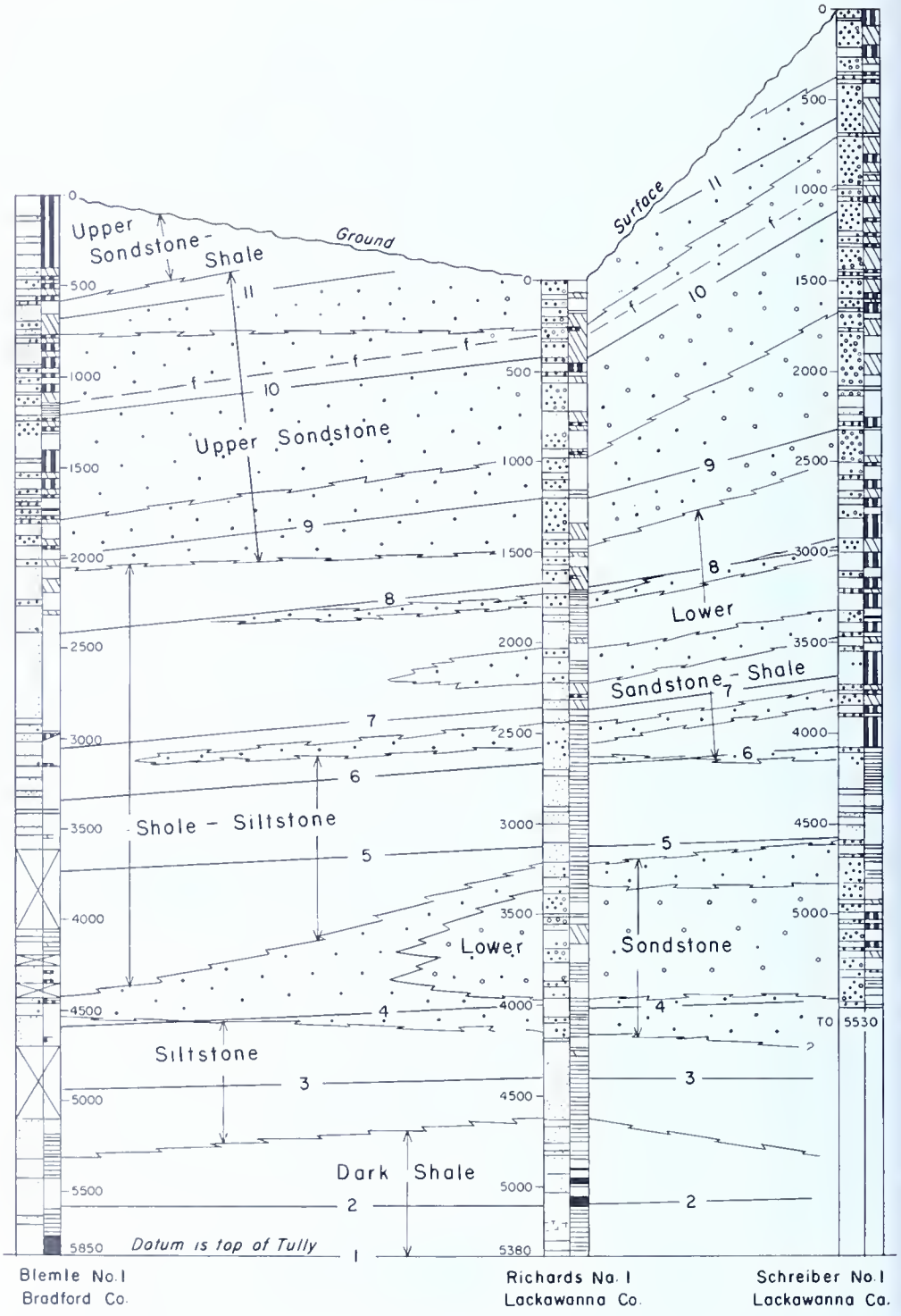
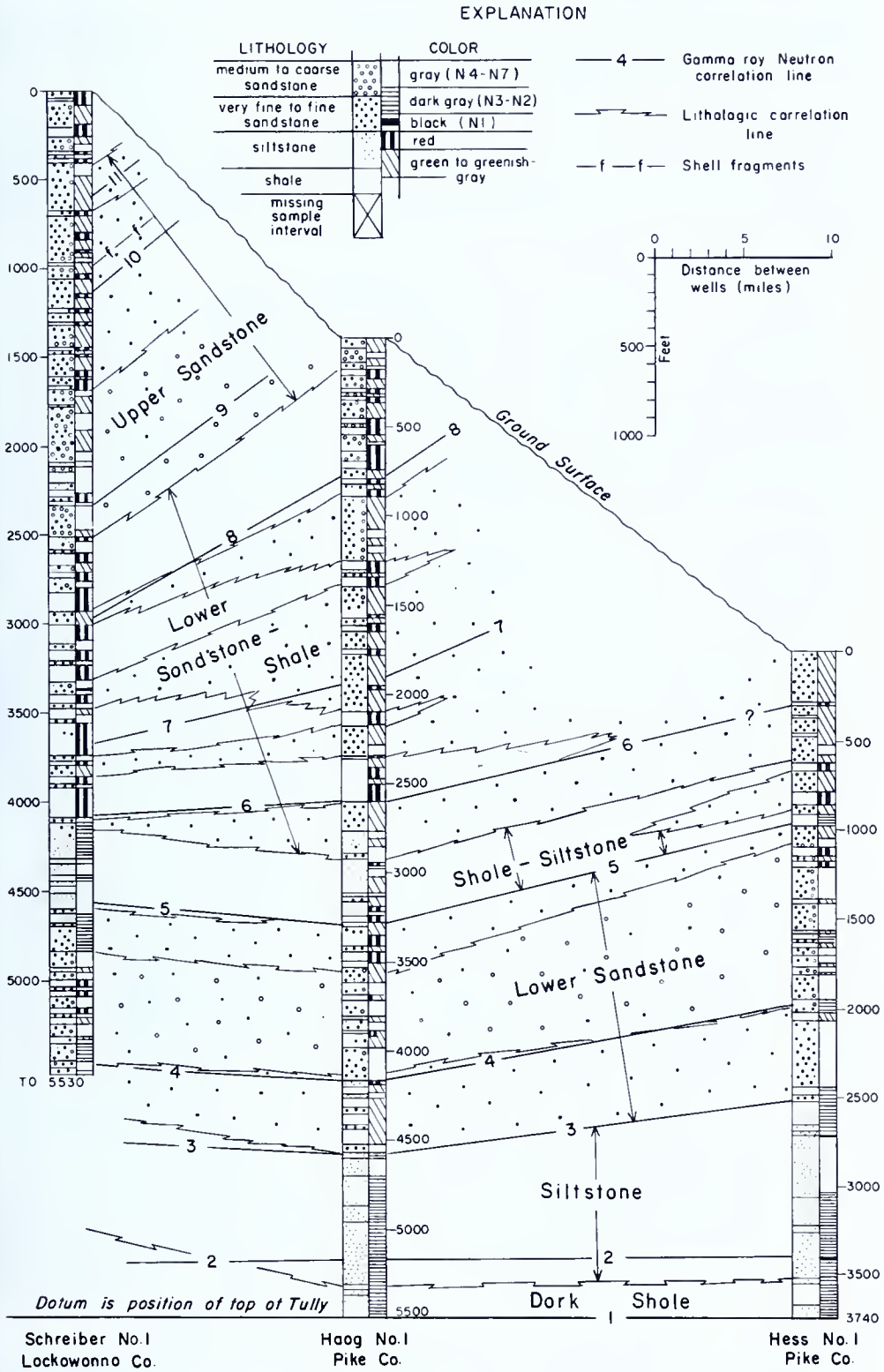


Figure 3. Correlation of Susquehanna Group (Upper Devonian) From Bradford County to Pike County, Pennsylvania.


EXPLANATION
LITHOLOGY
medium to coarse sandstone
very fine to fine sandstone
siltstone
shale
missing sample interval
COLOR
gray (N4-N7)
dark gray (N3-N2)
black (N1)
red
green to greenish-gray
4 Gamma ray Neutron correlation line
Lithologic correlation line
f f Shell fragments
0 5 10
Distance between wells (miles)
Feet
Upper Sandstone
Lower Sand'stone - Shale
Ground Surface
Shale - Siltstone
Lower Sandstone
Siltstone
Dork Shale
TO 5530
Datum is position of top of Tully
Schreiber No.1 Lackowonno Co.
Haog No.1 Pike Co.
Hess No.1 Pike Co.

being discussed are also close to time-stratigraphic markers because they coincide with the black shales.

Subdivision of Susquehanna Group by Rock Type (Figure 3)

Overlying the Tully is a dark-gray to black shale unit, thickest in the west in the Blemle and Richards wells, and thinning eastward in the Haag and Hess wells. The depth and thickness of the shale unit in each well is given in Table 1.

Table 1. *Interval and Thickness of dark shale unit.*

Blemle	*Richards*	*Schreiber*	*Haag*	*Hess*
5320–5850	4630–5380	Well does not	5310–5500	3510–3740
(530)	(750)	reach unit	(190)	(230)

A unit of dark-gray to gray siltstone and subordinate shale lies above the dark shale unit (see Table 2). With respect to the gamma ray correlation lines "2," "3," and "4," the siltstone unit rises stratigraphically

Table 2. *Interval and Thickness of siltstone unit.*

Blemle	*Richards*	*Schreiber*	*Haag*	*Hess*
4510–5320	4150–4630	Well does not	4570–5310	2520–3510
(810)	(480)	reach unit	(740)	(990)

to the west, thus becoming younger. The next unit upward is a sandstone sequence called the lower sandstone unit. It is thickest in the east and thins westward, almost disappearing in the Blemle well (see Table 3). Some medium- to rarely coarse-grained sandstone occupies the central

Table 3. *Interval and Thickness of lower sandstone unit.*

Blemle	*Richards*	*Schreiber*	*Haag*	*Hess*
4430?–4510	3220–4150	4600–5530+	3300–4570	965–2520
(80?)	(930)	(930+)	(1270)	(1555)

part of the sandstone unit and is not found as far west as the Blemle well. Red beds are common in the middle to upper part of the sandstone in the three eastern wells. Relative to gamma ray correlation lines "4" and "5" the red shale from 5000 to 5100 in the Schreiber well lies in the same position as green shale from 3565 to 3670 in the Richards and the red siltstone and shale from 4280 to 4350+ in the Blemle well.

Above the lower sandstone unit is a wedge of shale and siltstone. This gray to dark-gray unit is very thin in the Hess well and becomes extremely thick westward into the Blemle well. Depths and thicknesses are given in Table 4. The great thickening of this unit in the Blemle well is the result

Table 4. *Interval and Thickness of shale-siltstone unit.*

Blemle	*Richards*	*Schreiber*	*Haag*	*Hess*
2050–4430?	2615–3220	4200–4600	2920–3300	920–965
(2380)	(605)	(400)	(380)	(45)

of most of the lower sandstone unit grading into shale and siltstone and also because of a similar sandstone to shale change that occurs in the interval between gamma ray correlation lines "6" and "8" from the Richards into the Blemle well.

Much of the shale-siltstone unit found in the Blemle well is replaced eastward by a sequence called the lowet sandstone-shale unit (see Table 5).

Table 5. *Interval and Thickness of lower sandstone-shale unit.*

Blemle	*Richards*	*Schreiber*	*Haag*	*Hess*
Absent	1480–2615	2510–4200	180–2920	0–920
	(1135)	(1690)	(2740)	(920)

Significant environmental changes take place within this unit. The section found in the Richards well appears transitional between red beds to the east and slightly fossiliferous, marine shales and siltstones to the west. Greenish beds and traces of red are found in the sandstone-shale unit of the Richards well. Eastward into the Schreiber well section the marine aspect is replaced by a red bed sequence which thickens farther east in the Haag well. The thickening in the Haag is the result of greenish sandstones 150 to 300 feet thick interfingering with red shales.

The next overlying unit is green, gray, and red sandstone with subordinate red shale. Its boundaries are given in Table 6. The unit can be divided into three zones based on color: a lower and upper non-red

Table 6. *Interval and Thickness of upper sandstone unit.*

Blemle	*Richards*	*Schreiber*	*Haag*	*Hess*
580–2050	0–1475	408–2510	0–180	——
(1470)	(1475)	(2102)	(180)	

sandstone with some red shale. The boundaries of the three zones are marked by the irregular correlation lines. In the middle sandstone zone are beds of very fine- to coarse-grained sandstone containing fragments of limestone, dolomite, and shale. These are probably the "glomerates" of Willard (1939, p. 284), one of which has traces of crinoid columnals in the Richards and Blemle wells and shell fragments in the Schreiber well. This particular "glomerate" is marked in the cross section by a dashed line with the letter "f."

The highest unit found in the wells, the upper sandstone-shale unit, is differentiated from the underlying sandstone unit by an increase in the amount of red shale. It is 0 to 580 in the Blemle and 0 to 408 in the Schreiber well.

Subdivision of Susquehanna Group by Color (Figure 4)

The red beds of the Susquehanna Group can be divided into three units: an upper unit present from the Blemle to the Schreiber wells, a middle unit found mainly in the Schreiber and Haag wells, and a lower unit

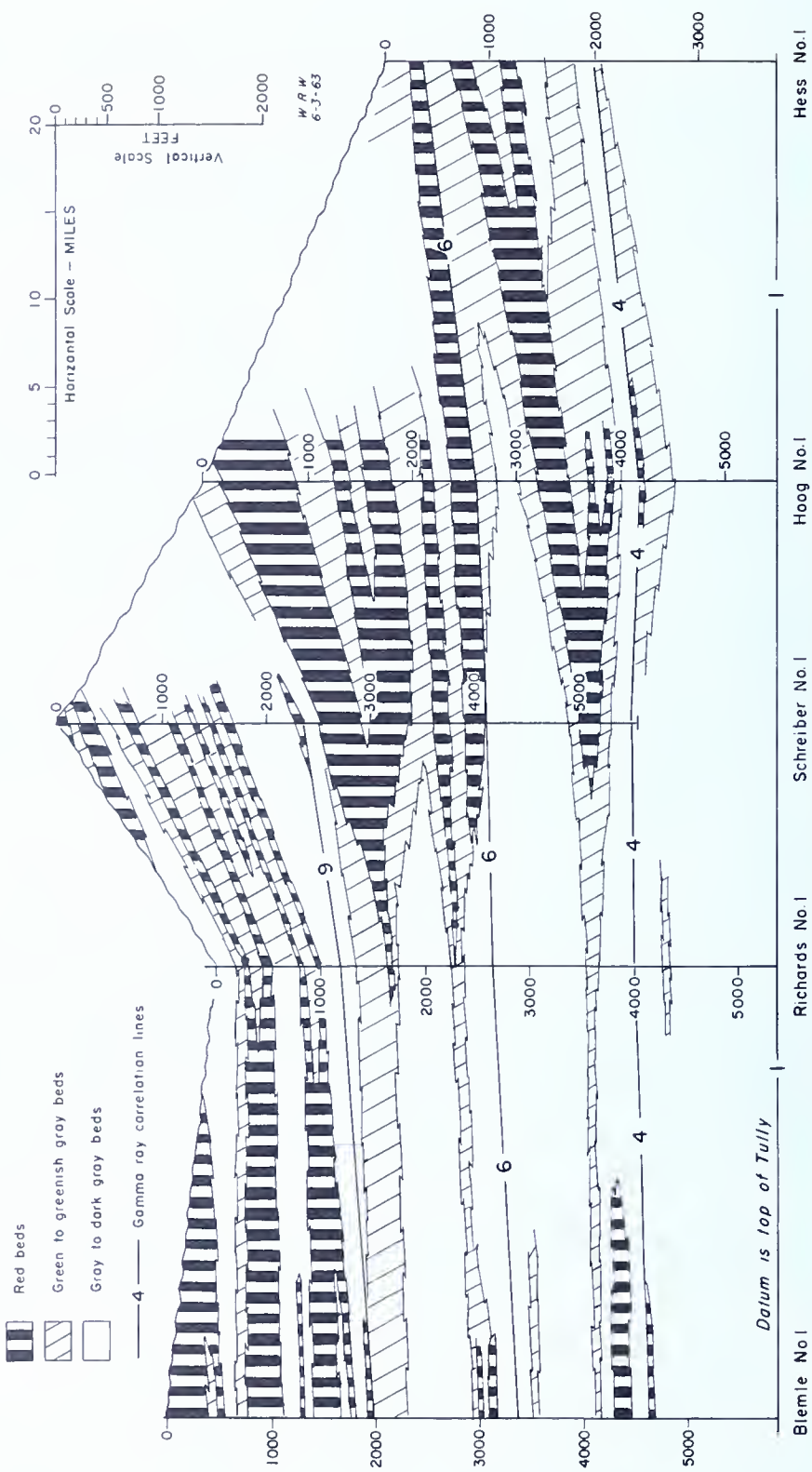


Figure 4. Stratigraphic relation of red to non-red beds within Susquehanna Group from Bradford County to Pike County, Pennsylvania

mostly in the Haag and Hess wells. The boundaries of the three units are given in Table 7. The bases of the red units tend to parallel the gamma ray

Table 7. *Red units of the Susquehanna Group.*

	Blemle	*Richards*	*Schreiber*	*Haag*	*Hess*
Upper	0–1810	0–960	0–1780	----	----
Middle	traces 2970–3170	traces 1630–2260	2510–4080	180–2600	0–300
Lower	traces 4280–4700	Not present	5010–5190?	3200–4190	620–1280

correlation lines, but the tops are more variable.

An intimate relationship seems to exist between the colors red and green. In most cases red is interbedded with green and green is interbedded with gray, but rarely are red and gray interbedded. This relation probably occurs laterally as well as vertically because green tongues in the Blemle and Richards wells extend eastward into red beds in the Schreiber well.

Formational Nomenclature of Susquehanna Group (Figure 5)

Figure 5 shows the subdivision of the Susquehanna Group using the terminology proposed by White (1881, 1882) and modified by Willard (1935, 1939). Within the upper and middle red bed units formational division has been based primarily on the presence or absence of red. For example, Mount Pleasant and Cherry Ridge are sandstones containing red beds and Elk Mountain and Honesdale are sandstones with few or no red beds. The Damascus is mostly a red shale and the Shohola is interbedded sandstone and red shale. In this paper the Shohola is a lateral facies of the Damascus and both the Shohola and Damascus are underlain and replaced westward by the New Milford shale and siltstone.

Willard (1939) divided the siltstone and lower sandstone unit into the Delaware River Flags above and the Trimmers Rock sandstone below. The boundary between them is the lowest red bed, the Analomink red shale. Thus he implied that red beds do not occur in the Trimmers Rock. West of the Schreiber well red beds almost completely disappear from the siltstone unit and lower sandstone unit and the whole interval can be referred to the Trimmers Rock. Where red beds are common in the Delaware River Flags perhaps the name Oneonta is more appropriate.

The dark shale unit above the Tully includes the Brallier, Harrell, and Burket Formations.

Correlation of Subsurface with Lehigh Gap and Ransom Quadrangle Outcrop Sections (Figure 6)

The Haag well and the upper part of the Schreiber well can be correlated with the Lehigh Gap section, Carbon County. Description of the

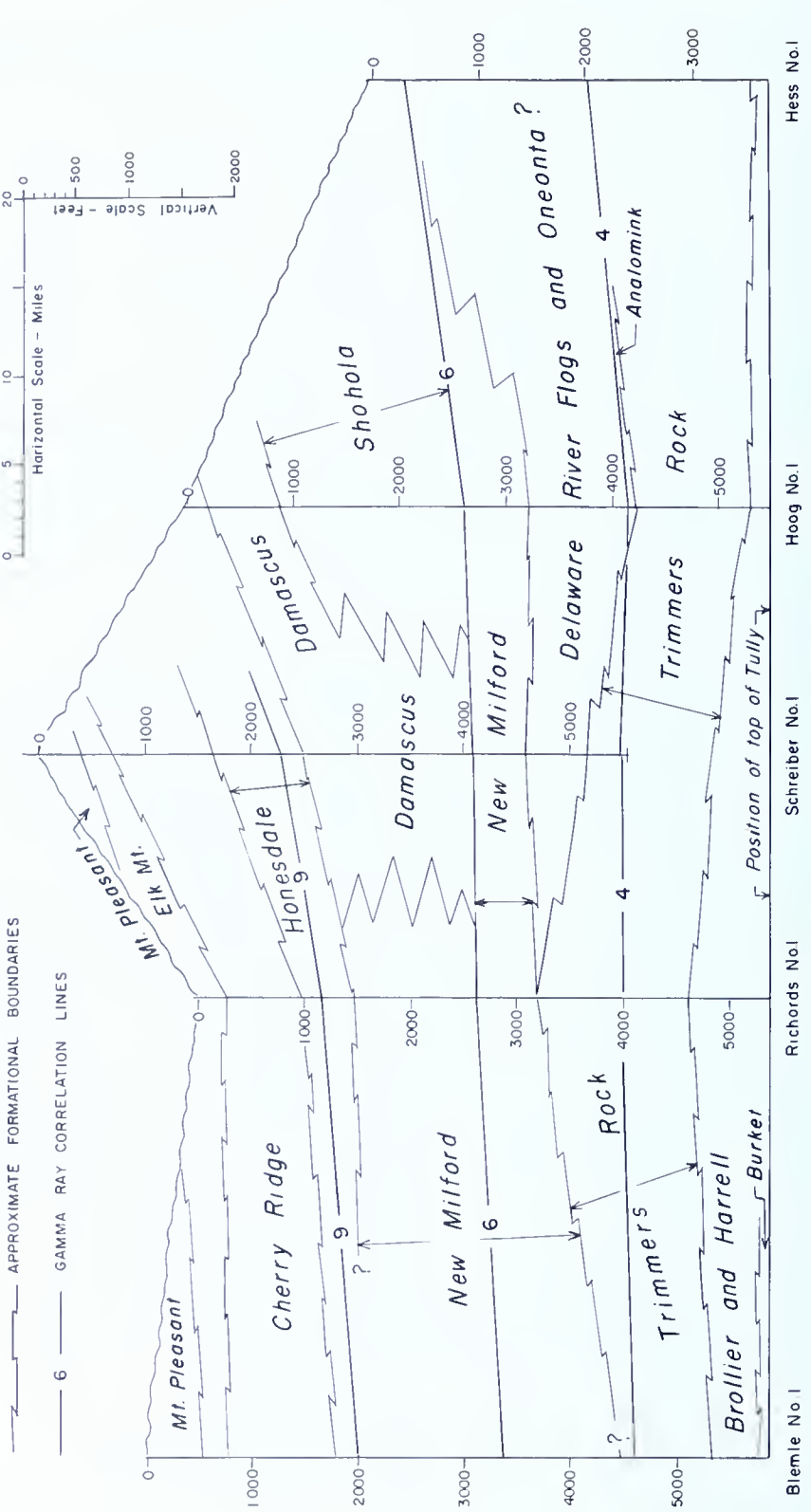


Figure 5. Subdivision of Susquehanna Group using terminology of White and Willard

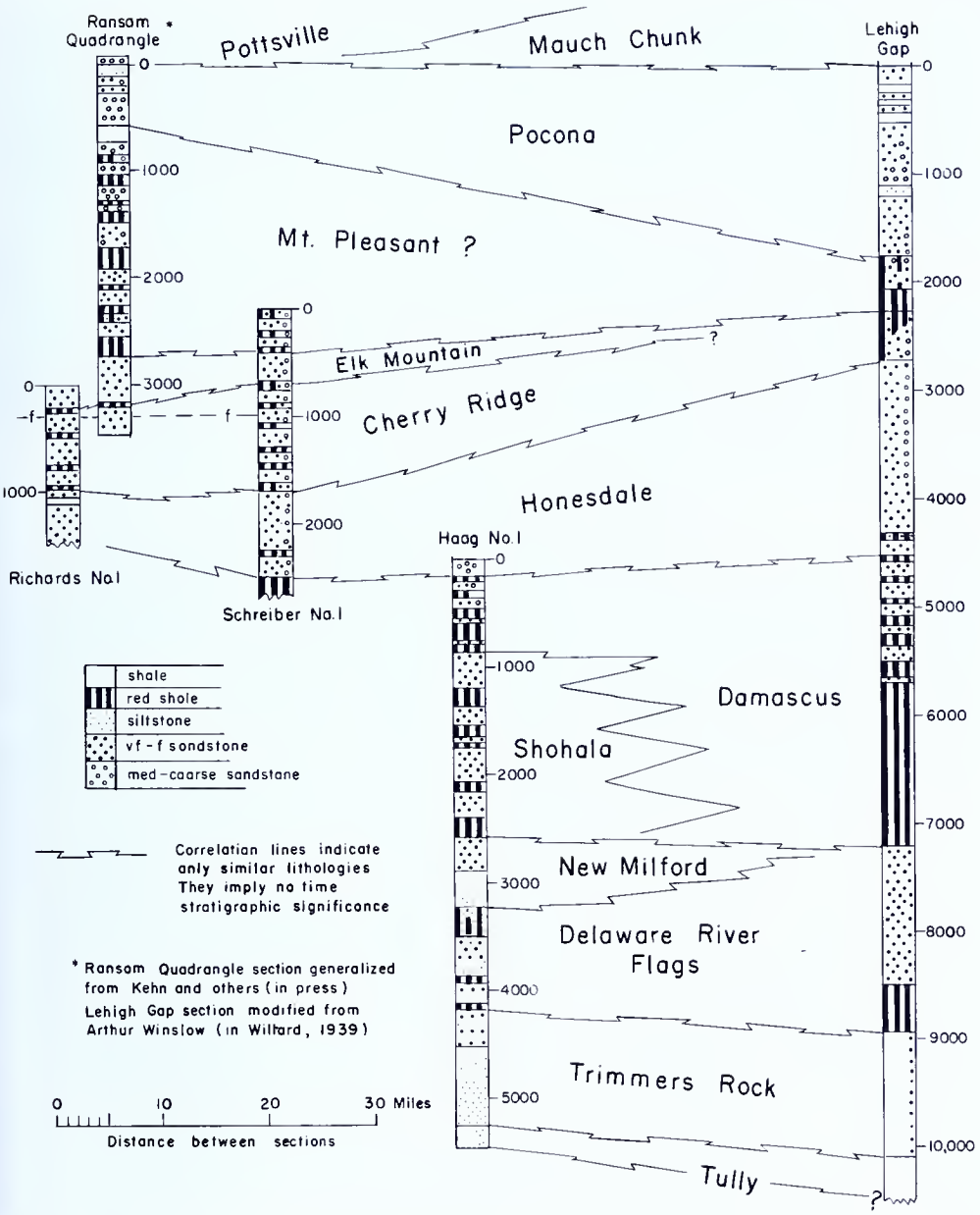


Figure 6. Tentative correlation of Subsurface with outcrop sections at Lehigh Gap, Carban County, and Ransom Quadrangle, Lackawanna County, Pennsylvania.

section is taken from Winslow (in Willard, 1939, p. 265). Below the Honesdale, thicknesses and lithologies of the Haag well and Lehigh Gap section are comparable. In the Schreiber well the Elk Mountain, Cherry Ridge, and Honesdale are a unit which is represented in the Lehigh Gap by a thick Honesdale and thin Cherry Ridge. The Honesdale and Cherry Ridge may be in part equivalent and the Elk Mountain in the Schreiber well probably passes southward into the Cherry Ridge at Lehigh Gap.

Kehn and others (in press) related the Richards well to the nearby outcrop sections which they measured along the Susquehanna River in Lackawanna and adjacent counties. They found approximately 2500 feet of Susquehanna Group above the Richards well. The Ransom quadrangle columnar section in Figure 6 places almost all of that thickness in the Mount Pleasant.

Correlation of the Ransom section with the Lehigh Gap section shows thinning of the Pocono northward and concomitant thickening of the Mount Pleasant. However, the combined thickness of the Pocono and Mount Pleasant varies only slightly. This relationship supports the idea of a facies change occurring between the upper Mount Pleasant and the lower Pocono, but, on the other hand, it does not condemn the possibility of an unconformity between the two.

SUMMARY AND CONCLUSION

Table 8 integrates the correlations by rock type and by color with the terminology of White (1881, 1882) and Willard (1935, 1939) in the Upper Devonian of northeastern Pennsylvania. The use of these formational names is intended to demonstrate one rock-stratigraphic way in which the Susquehanna Group can be partitioned.

Gamma ray-neutron logs are valuable aids in subdividing the group. It is suspected, but certainly not proven, that these radioactivity correla-

TABLE 8

INTERRELATIONSHIP OF ROCK-TYPE, COLOR, AND FORMATIONAL UNITS WITHIN THE SUSQUEHANNA GROUP

Rock Units	Color Units	Formations
Upper Sandstone - Shale Unit	Upper Red Unit	Mount Pleasant
Upper Sandstone Unit: Upper zone		Elk Mountain
Upper Sandstone Unit: Middle zone		Cherry Ridge
Upper Sandstone Unit: Lower zone		Honesdale
Shale-Siltstone Unit: Lower Sandstone Shale Unit	Middle Red Unit	New Milford: Damascus; Shohola; Del.
Lower Sandstone Unit	Lower Red Unit	River Flogs; Anolomink; Trimmers Rock
Siltstone Unit		
Dork Shale Unit		Brollier, Horrell and Burket
Limestone		Tully

tion lines are closer approximations to lines of contemporaneity than rock or color correlations alone. Another correlation, equally as valid as the rock-stratigraphic one shown in Table 8, can be established with the gamma ray-neutron log. A rock unit bounded by radioactivity correlation lines can be considered as a time-rock unit and lateral variations within this unit can be given formational or member names.

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Post-Rhinestreet Stratigraphy in the Sayre and Towanda Quadrangles, Pennsylvania: A Progress Report

ABSTRACT

Five post-Rhinestreet (Upper Devonian) formations and two members have been recognized during reconnaissance mapping in the Sayre and Towanda quadrangles, Pennsylvania. In ascending order, they are: Gardeau Formation including the Corning Member at the top, Formation 'A', Formation 'B' including Member 'B-1' at the base, and Formations 'C' and 'D'.

INTRODUCTION

The purpose of this report is to describe the sequence and composition of post-Rhinestreet (Upper Devonian) units recognized during reconnaissance mapping in the Sayre and Towanda quadrangles, Pennsylvania (Figure 1). Listed in ascending order, the units are: Gardeau Formation, including the Corning Member at the top, Formation 'A', Formation 'B' including Member 'B-1' at the base; and Formations .C' and 'D' (Figure 2). Subsurface data have been used to supplement information from widely scattered exposures during mapping. Specific procedures are discussed by Woodrow and Nugent (1963, p. 71–73).

Formations 'A' through 'D' have been designated informally until the utility of established terminologies is determined. Straight forward application of terms such as: Damascus, Honesdale, and Cherry Ridge (Willard, Swartz, and Cleaves, 1939, p. 291); or: Wellsburg, Mansfield, and Blossburg (Cooper and others, 1942) have been hampered by lack of accurate descriptions.

This study is being conducted as graduate research at the University of Rochester under the Supervision of Dr. R. G. Sutton. Grants from the Geological Society of America have been used to defray field and laboratory expenses.

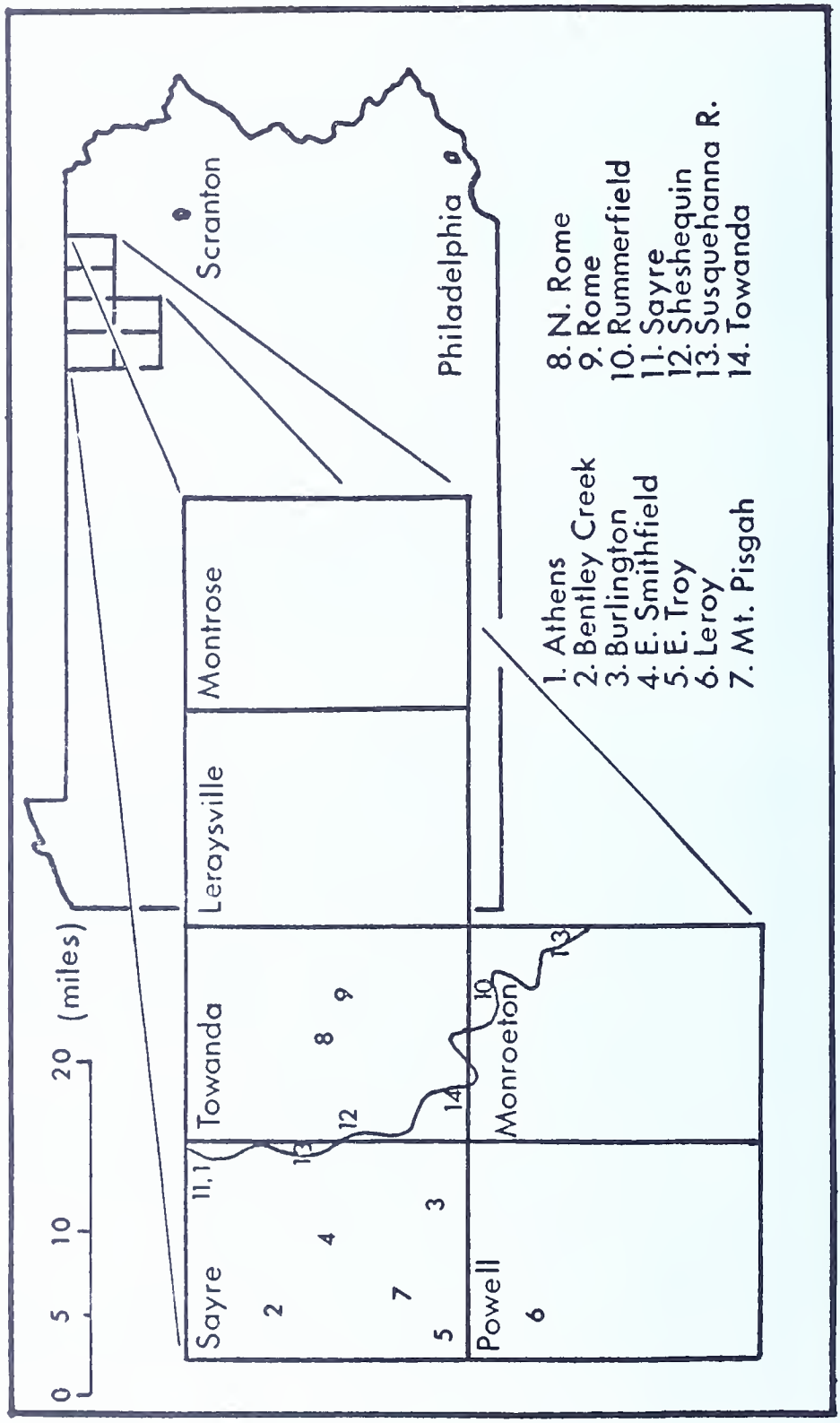

Figure 1. Locations Referred to in Text.

FORMATIONS MAPPED

Gardeau Formation

The Gardeau is recognized in the restricted sense proposed by Sutton (1963). It is defined as the strata above the Roricks Glen Member of the Rhinestreet Formation and includes the Corning Member at the top. Gray siltstones and sandstones and gray silty shales make up the formation. Fossils are common in scattered horizons; those encountered include forms listed as 'typical Chemung fauna' in older reports. Stratification is regular although flow rolls and convolute laminae are not uncommon in argillaceous beds.

Subsurface data indicate the Gardeau thins from 550 feet near Bentley Creek village to less than 450 feet southeast of Towanda. Typical rock types and fauna may be observed in the cut beside the paved road, 3.5 miles southeast of Sayre on the east side of the Susquehanna River, at elevation 800 to 900 feet; and in the east bank of Wysox Creek at the village of Rome at elevation 790 feet. The Corning Member is exposed in Bullards Creek, one mile southeast of North Rome village at elevation 960 feet; and in Terwiliger Run, 1.8 miles northeast of Bentley Creek village at elevation 1430 feet.

Formation 'A'

Included within this unit are strata between the Corning Member of the Gardeau and the base of a sequence of dark-grey and olive shales 1050 feet above the Corning stratigraphically. Considerable lithologic variety exists within the formation. At the base are 350 to 450 feet of gray sandstones, siltstones, and shales similar to strata in the underlying Gardeau. Above this are approximately 250 feet of light-gray, medium-grained, flaggy sandstones and olive, silty shales. Finally, 400 to 500 feet of interbedded reddish-gray sandstones and siltstones, and gray-blue, silty shales occur at the top. Bedding surfaces in this upper sequence are often marked by a profusion of well developed tracks, trails, burrows, and ripple marks. Groove casts are noted on the underside of sandstones; cross-bedding is common.

Fossils occur throughout the formation, in some instances as thick beds of coquinite. Brachiopods such as *Athyris* sp. and *Cyrtospirifer* sp. have been noted as well as numerous crinoid stems and fish plates. At some exposures broken and abraded shells are found in calcareous, dull-red sandstones. In addition to the coquinites, conglomerates of well-rounded quartz pebbles interbedded with coarse-grained orthoquartzitic sandstones occur within Formation 'A'. These fossil-rich and pebbly rocks have long attracted the attention of geologists working in the area due to their unique character, widespread areal distribution, and ap-

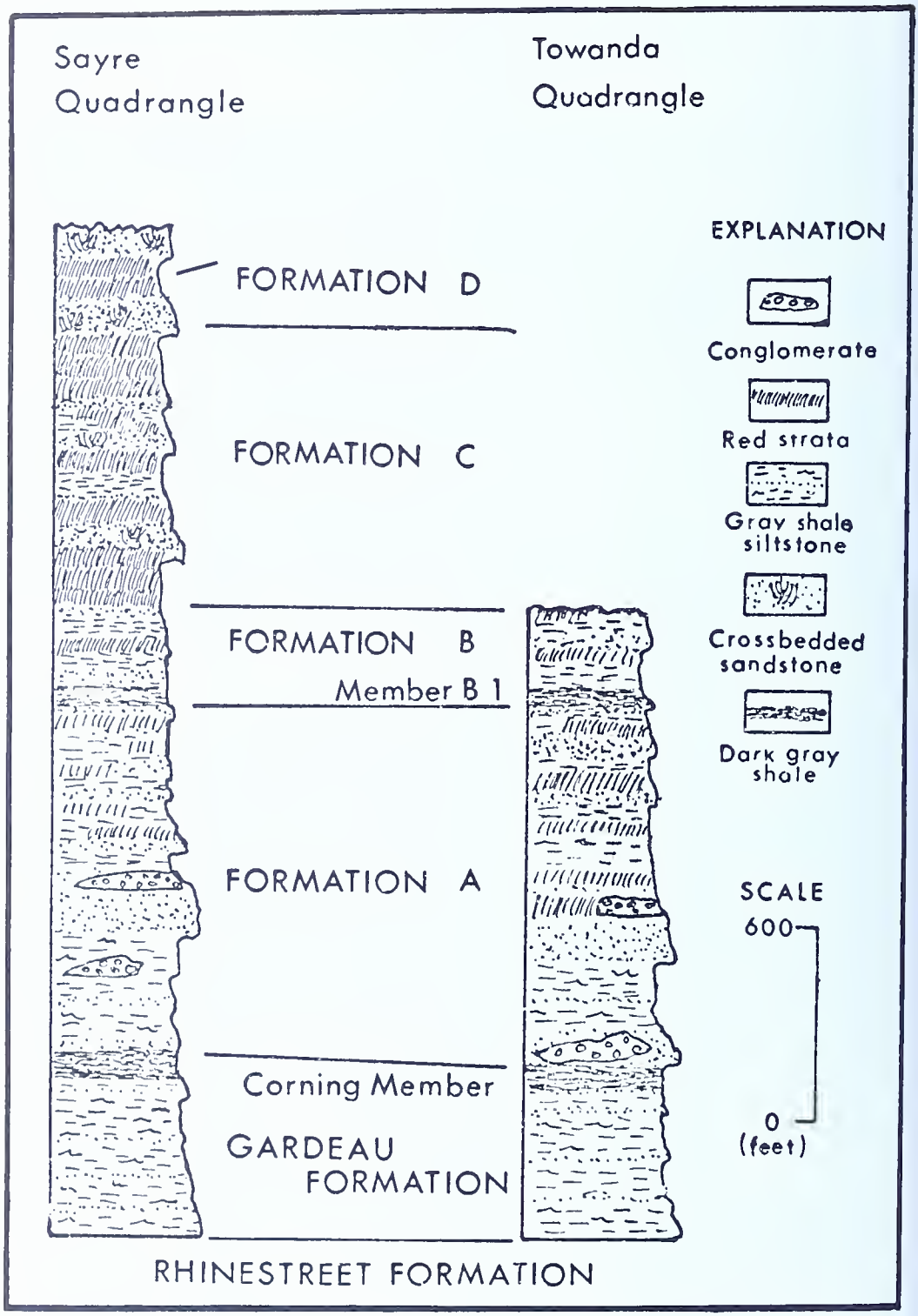

Figure 2. Composite Columnar Sections.

parently restricted stratigraphic position. Two have been recognized formally as the Luthers Mills Coquinite (Willard, 1936) and the Fall Creek Conglomerate (White, 1881). However, surface and subsurface data indicate these rocks are small lenses and that other, similar lenses occur at widely separated areal and stratigraphic positions within Formation 'A'. They appear to have slight value as stratigraphic markers.

Coquinites may be observed in place on the north side of U. S. Route 6, 0.6 miles east of the road junction in Burlington village at elevation 920 feet; and in the cliffs, 0.6 miles northeast of the Sheshequin-Towanda Bridge at elevation 1140 feet. Conglomerates are exposed in Fall Creek, 2.4 miles southeast of Bentley Creek village at elevation 1320 feet (type section of the Fall Creek Conglomerate); in a southeasterly flowing tributary of Tomjack Creek, 1.4 miles southwest of East Smithfield Village at elevation 1175 feet; and in a road cut, 3.4 miles northeast of Athens Borough (1.3 miles northwest of Litchfield village) at elevation 1290 feet.

Formation 'B'

As mapped, Formation 'B' includes the strata between the base of Member 'B-1' and the base of the thick red beds in the overlying unit. Blue-gray, silty shales and light-gray, medium-grained sandstones are the most common rock types; reddish-gray sandstones, similar to those in the upper parts of Formation 'A' are minor constituents. Ripple marks, tracks, trails, and burrows mark bedding surfaces; cross-bedding is noted in the sandstones. Fossils are not common but have been found in scattered horizons; typical Chemung forms predominate. The unit is too poorly exposed to allow more exact determination of composition.

A sequence of dark-gray shales included at the base of the formation and defined as Member 'B-1' has been traced as a persistent horizon. When weathered, the shales display excellent fissility. The sequence may be observed at the base of the quarry, 0.75 mile south of Ayers Crossroads, west of the paved road to Burlington at elevation 1330 feet; and in a southerly flowing stream in the Monroeton quadrangle (Figure 1), 0.8 mile south of Rummerfield village at elevation 1180 feet.

Formation 'B' is estimated to be 250 to 300 feet thick.

Formation 'C'

Brick-red to reddish-purple sandstones, mudstones, and shales compose a major part of Formation 'C' making it distinct from underlying units. Minor amounts of greenish-gray, medium-grained sandstones and green shales occur throughout. Fossils other than plant fragments have not been observed in any of these strata. In part, the apparent lack of fossils may be explained by the scarcity of exposures at which the rocks may be examined.

Within the study region, Formation 'C' is limited to the lower slopes of Mt. Pisgah where evidence of its presence is given by the extensive red coloration of soils and unpaved roads. In a northerly flowing stream, 0.5 mile south of Leroy village (Figure 1), the unit is exposed from elevation 1100 feet to 1690 feet and is at least 850 feet thick. Extensive lateral exposures occur along U. S. Route 6, 2.3 miles west of East Troy village and in the banks of Sugar Creek at the same location. Small parts of the formation are exposed in the road cut and westerly flowing stream one mile north of East Troy on the paved road parallelling Leonard Creek at elevation 1020 to 1100 feet.

Formation 'D'

The youngest beds recognized have been assigned to this unit. The base of the Formation is placed at the bottom of the lowest, major (more than 25 feet thick), greenish-gray, coarse-grained sandstone appearing in the section. The top is marked by the lower limit of light-gray, medium-grained sandstones. Greenish-gray sandstones of the type noted at the base of the unit make up more than 50 per cent of its total composition, the remainder is composed of red and green, silty mudstones, siltstones, and shales. Cross-bedding is a prominent feature; individual beds are one to three inches thick, planar, up to five feet long, and inclined at angles of 15 to 25 degrees. Lower bedding surfaces of the sandstones found in contact with red strata are irregular with relief of several inches. Sandstones contain shale-chip conglomerates in their lower parts and grade upward into red siltstones and shales. The sequence, greenish-gray sandstones grading upward into red siltstones and shales, is repeated several times in the formation on scales from several feet to more than 175 feet.

Part of Formation 'D' underlies the higher slopes of Mt. Pisgah. There, sandstones within the formation form prominent benches. Thickness could not be determined within either quadrangle, but was measured in the stream south of Leroy mentioned above. In this stream section, the formation is completely exposed between 1690 feet and 2060 feet elevation; its thickness is 800 feet.

Units Higher Than Formation 'D'

A few hundred feet of rock are poorly exposed above Formation 'D' in the stream south of Leroy and higher on the mountain south of the stream. A prominent, quartz-pebble conglomerate, estimated to be more than 30 feet thick, forms low cliffs on the highest knobs of the mountain, one-half mile southwest of the stream section. South of these cliffs, stratigraphically above the conglomerate, coal beds are present.

SUGGESTED CORRELATIONS

Relationships between units exposed in the study quadrangles are suggested in Figure 2. The Corning Member of the Gardeau Formation has been traced from Towanda, north, into the units of the Upper Devonian standard section. Based on knowledge of the persistence and stratigraphic position of the Corning, Formation 'A' appears to occupy a position stratigraphically equivalent, at least in part, to that occupied by the West Hill and Nunda Formations in New York.

Correlations between Formations 'B', 'C', and 'D' and the units recognized above the West Hill and Nunda in south-central New York, the Hanover, Wiscoy, and Perrysburg (Twigg, 1961), are not suggested here. Comparison of the higher units exposed in Pennsylvania with those of New York shows such dissimilar compositions and thicknesses that it becomes apparent correlations in which they are involved must be based on more information than is now available.

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Correlation of Upper Devonian Strata in South-central New York

ABSTRACT

The Upper Devonian stratigraphy of the Watkins Glen-Corning area is summarized and correlation across south-central New York is described. The stratigraphic units are defined by the position of black-shale tongues that split the Chemung and penetrate the Catskill lithofacies to the east.

Basin, slope, shelf and terrestrial environment are defined by changes in thickness of strata, grain size, sorting and mineral composition. Stages in the cyclical development of the delta complex are briefly described.

INTRODUCTION AND ACKNOWLEDGEMENTS

The Upper Devonian in the vicinity of Watkins Glen-Corning consists of approximately 2,000 feet of shales and siltstones (Portage lithofacies) overlain by 2,000 feet of mudstones and sandstones (Chemung lithofacies), and topped by 400 feet of red and green sandstones and shales (Catskill lithofacies). Near Walton the Upper Devonian is more than 3,600 feet thick and composed almost entirely of the Catskill lithofacies (Figures 1 and 2). This paper is concerned with the stratigraphy of the intervening area. The stages in the development of the delta complex and paleoenvironments are also considered.

In western New York, the Upper Devonian consists for the most part of the Portage lithofacies, conveniently subdivided by a number of black shales that had been readily identified and traced into central New York by Clarke, Luther, Chadwick and others. The shales form tongues which were once thought to terminate where the Portage lithofacies changed to the Chemung lithofacies in south-central New York. Subdivisions of the Chemung were accomplished by means of faunal zones by H. S. Williams and others (1909). Efforts to subdivide the Catskill, although largely unsuccessful, were based primarily upon subtle lithologic variations. The major stratigraphic problems in the 1940's and 1950's were, primarily, the correlation of the stratigraphic units of the Portage lithofacies with those of the Chemung lithofacies based upon faunal zones. W. deWitt, G. W. Colton (1959), and this writer (Sutton, 1959) succeeded in carrying the

Figure 1. Index map showing location of quadrangles

black shales into the Chemung. Although minor discrepancies occurred, the correlation was effectively achieved and carried eastward to the Dryden-Waverly area by Sutton, Humes, Nugent and Woodrow (1962). Additional reconnaissance mapping by this writer has carried the shales east of the Oneonta-Deposit area where they were found to penetrate the Catskill lithofacies.

During the course of these studies, several methods of correlation were investigated; faunal zonation (including *Cyrtospirifer chemungensis, Cornellites chemungensis,* and hystrichopherids), heavy mineral zonation, and lithostratigraphic zonation based on the black-shale tongues. The black shales were considered to be most useful because they could be readily identified in the field and in the subsurface without extensive sample preparation as with the hystrichopherids and heavy minerals. Primarily, however, they conveniently split the three lithofacies and allow the direct comparison of the intervening lithologies across southern New York State. In addition, the shale tongues appear to be the closest ap-

proach to time planes. The subdivision of the delta complex in this manner allows quantitative sedimentological and paleoecological studies to be undertaken that would be exceedingly difficult or otherwise impossible. There is no reason to assume that the black shale tongues could not be readily identified in the Devonian of Pennsylvania, thereby providing a convenient correlation with the New York Standard and at the same time shedding considerable light on the complex facies changes common to both States.

Most sincere thanks are extended to the New York State Science Service for its financial support. The late Professor Harold Alling kindly made many of his petrographic analysis available to the writer.

SUMMARY OF THE STRATIGRAPHY

Terminology

The stratigraphic nomenclature used here emphasizes the lateral continuity but inadequately defines the lateral facies changes that occur between the black shale tongues. The reconnaissance nature of much of the mapping, particularly that east of the Dryden-Owego area, makes this approach necessary. Correlations, stratigraphic terminology, thicknesses and dominant lithofacies are shown in Figure 2.

Genesee Group

The Genesee Group, as defined by Chadwick (1935, p. 352), consists of the strata that occur between the top of the Tully and the base of the Naples Group (Middlesex). It is divided into the Geneseo and Ithaca Formations in the west and represented by the Oneonta in the east.

Geneseo Formation—is predominantly black shale in central New York. It is approximately 135 feet thick at Cayuga Lake but thins eastward and becomes a dark gray shale. F. W. Fletcher and this writer have tentatively identified its eastward equivalent on the Catskill Front where it penetrates the Catskill lithofacies.

Ithaca Formation—was redefined by Sutton, Humes, Nugent and Woodrow (1962, p. 392) to include the Penn Yan, Genundewa, and West River Members in the Seneca Valley and west. In the Ithaca-Harford area the Ithaca is composed of the Sherburne, Renwick, and Treman Members. East of Harford the Sherburne, Otselic, and Cincinnatus Members are recognized.

Oneonta Formation—is defined by the presence of red shales and sandstones that form but 20 percent of a tongue of essentially non-marine strata that lie below the Kattel and above the Otselic. Gray sandstones,

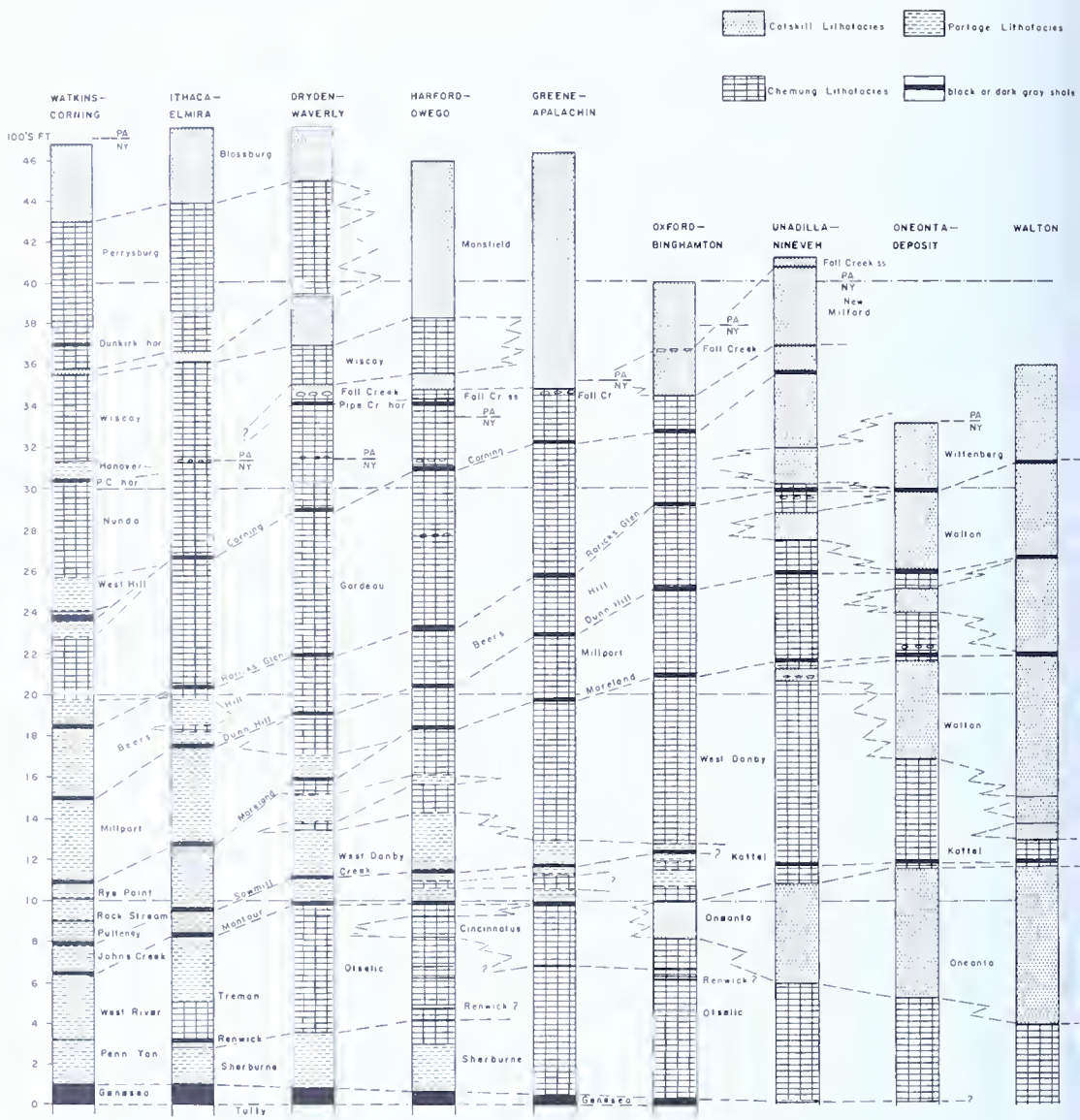

Figure 2. Composite Stratigraphic Sections

gray and green shales, red shales and sandstones, and conglomerates, summarily called the Catskill lithofacies, distinguish it from other members of the Ithaca. The Oneonta extends from Brisben (Chenango Valley) to the Catskill Front. At Brisben it is approximately 250 feet thick. Thicknesses of 550, 650, and 800 feet are assigned to it in the Unadilla, Oneonta, and Walton quadrangles respectively.

Naples Group

In the Watkins Glen-Walton area, the Naples Group is defined as overlying the Genesee Group and underlying the West Falls Group. Here it is

composed of the marine Middlesex and Sonyea Formations, and correlated with the lower part of the Walton Formation to the east.

Middlesex Formation—is approximately 160 feet thick and divided into three members: Montour (black shales), Johns Creek (gray shales and siltstones), and Sawmill Creek (black shales). East of Greene the upper and lower members are not recognizable and the formation is represented by the Kattel Member, dark gray to black shales marked by *Leiorhynchus globuliformis.*

Sonyea Formation—as redefined by Colton and deWitt (1958) consisted of the Middlesex Black Shale and Cashaqua Shale Members. This writer prefers the formational rank for the Middlesex but recognizes the need of a formational status for the post-Middlesex-pre-Rhinestreet strata. The name Sonyea is used here but restricted to that interval. It is represented by the Cashaqua Shale Member in western New York, the Pulteney, Rock Stream, and Rye Point Members in west-central New York and the West Danby Member in south-central New York. The Sonyea thickens from approximately 300 feet in the Seneca Valley to over 800 feet in the Oxford quadrangle.

West Falls Group

The West Falls Formation was defined by Pepper, deWitt, and Colton (1956) as including the strata from the base of the Rhinestreet to the base of the Pipe Creek in western New York. This writer follows Rickard's modification (in press) by elevating the term to that of a Group so that the numerous subdivisions may be more conveniently placed in formations and members across much of southern New York. The Rhinestreet, Gardeau, West Hill, and Nunda Formations are recognized.

Rhinestreet Formation—in western New York consists of black shales for the most part but eastward it splits into a series of tongues interbedded with soft gray shales and thin siltstones. In the Elmira-Owego area the gray shales and siltstones (Portage lithofacies) change rather abruptly into the Chemung lithofacies as described by Woodrow and Nugent (1963, p. 59–76). The Moreland (black shale), Millport, Dunn Hill (black shale), Beers Hill, and Roricks Glen (black shale) Members are recognized. This writer has traced the members from Owego to Walton where the shale tongues are still dark gray and penetrate the Catskill lithofacies, correlating with the upper part of the Walton Formation.

Gardeau Formation—is recognized as overlying the Rhinestreet and represents the eastward equivalents of the lower Angola Shale, as defined by Chadwick (1933). In the Corning area it represents the Chemung litho-

facies but changes, in part, to the Catskill lithofacies in the Deposit area. The Catskill there has been correlated with the Wittenberg Conglomerate to the east. The Corning Member is recognized at the top of the Gardeau and is composed of dark-gray shales, well displayed on N. Y. 17 just south of the Chemung River and west of Corning. The Corning has been traced into the Nineveh quadrangle where it penetrates the Catskill lithofacies.

West Hill and Nunda Formations—overlie the Gardeau and near Corning may be distinguished from each other by the presence of cross-laminated siltstones marked with flute casts in the former and thick sandstones with flow rolls in the latter, according to Twigg (1961). East of Corning these criteria fail to hold because the "West Hill" assumes the same characteristics as the Nunda at Corning. The Nunda is characterized by the Chemung lithofacies in the Corning quadrangle, its eastward equivalents lie in northern Pennsylvania south of Waverly and Owego, and its Catskill equivalent, tentatively the New Milford, occurs south of Binghamton.

Java Group

Following the terminology in the preliminary draft of the Correlation of Devonian Rocks by Rickard, the term "Java Group" is employed for strata that lie above the Nunda and below the Dunkirk in the vicinity of Corning. From the base, the following are recognized: Pipe Creek horizon, Hanover Shale, and Wiscoy Formation. Twigg (1961) identified the Hanover and Wiscoy but failed to find exposures of the Pipe Creek in the Corning quadrangle. He found 30 feet of sandstones and red shales (Catskill lithofacies) in the upper Wiscoy. Woodrow (personal communication) discovered dark-gray shales in the Sayre quadrangle that correlate with the base of the Hanover. Overlying the shales is the Fall Creek Conglomerate. Thus it would appear that the Fall Creek is approximately correlative with Pipe Creek, the scattered reds just above the Fall Creek would then correlate with the reds in the upper Wiscoy and the overlying marine strata would be equivalent to the lower Perrysburg. This writer has tentatively applied the name Mansfield to the Catskill lithofacies that form a thin tongue in the upper Wiscoy near Corning and overlie the Fall Creek.

Canadaway Group

The lower portion of the Canadaway Group is confined to the hills in the southwestern part of the Corning quadrangle, according to Twigg. Its eastward marine equivalents are believed to extend into the Sayre quadrangle but east of there they are represented by the Catskill lithofacies of the Mansfield Formation.

ENVIRONMENTAL RECONSTRUCTION

Introduction

Seven basic lithologies with variations and gradations are recognized in the field. They are (1) black shales, (2) gray shales, (3) siltstones and fine-grained sandstones, (4) mudstones, (5) greenish-gray sandstones (non-marine), (6) conglomerates, (7) limestones, (8) red shales and (9) red standstones. They tend to form mutually exclusive groups and if considered with their associated sedimentary structures and fossil assemblages are summarized by the terms, Portage, Chemung and Catskill. Of these (1), (2), rarely (3), and (7), with thin-shelled pelecypods, ammonoids, and a few species of small brachiopods help define the Portage. However, (3), (4), and rarely (6), with brachiopods, gastropods, "flow rolls", ripple marks, and cross-bedding characterize the Chemung. Finally, (5), (6), (8), and (9), large-scale cross-bedding, "current" lineation, and absence of marine fossils distinguish the Catskill.

All of the evidence to date indicates that each facies represents a distinctly different environment. The Portage represents deposits in basin and slope environments, the Chemung a shelf environment, the Catskill a strand line and continental environment. Changes in thickness of the stratigraphic units, mineralogy and lithologies allow identification of distinct stages in the development of the delta complex.

Mineral composition

Variation in mineral composition of 4 rock types is considered in somewhat greater detail and shown in the table below.

Mineral(s)	*Sandstones & Siltstones*	*Gray Shales*	*Black Shales*	*Limestones*
Quartz	36.2%	5.1%	5.1%	4.3%
Feldspars	0.7	0.2	0.0	0.1
Carbonates	10.0	8.1	2.8	82.6
"Clays"	43.6	81.4	88.4	10.7
Micas	5.4	0.2	0.2	0.3
Opaques	4.0	4.3	3.3	1.6
Misc.	0.1	0.7	0.2	0.4

Sandstones and siltstones based on 41 analyses; gray shale on 21 analyses; black shales on 13 analyses; limestones on 13 analyses.

Illite and kaolinite are combined as "clays". Detrital and authigenic carbonate are similarly combined. Micas include biotite, chlorite, and muscovite. If only the quartz, "clay", and carbonate content is considered, the field identification for each rock type is quite consistent (see

Figure 3). The term limestone has been applied to all specimens containing more than 45 percent carbonate, shale to those with more than 80 percent "clay" minerals, the terms siltstone (including flagstone) or sandstone to those with more than 20 percent quartz (larger than 0.01 mm. nominal diameter). With one exception, the siltstones contained less than 60 percent quartz and in most of these the balance was composed of "clay" minerals. The trend of points for the limestones carries them over to the siltstones and sandstones but not into the shales. Thus the limestones are considered to be genetically related to the siltstones and sandstones rather than the shales with which they are interbedded. The shoreward equivalents of the limestones should be sandstones, siltstones, or bioclastics. Similarly a gradation exists between the gray shales and sandstones but not between the sandstones and black shales.

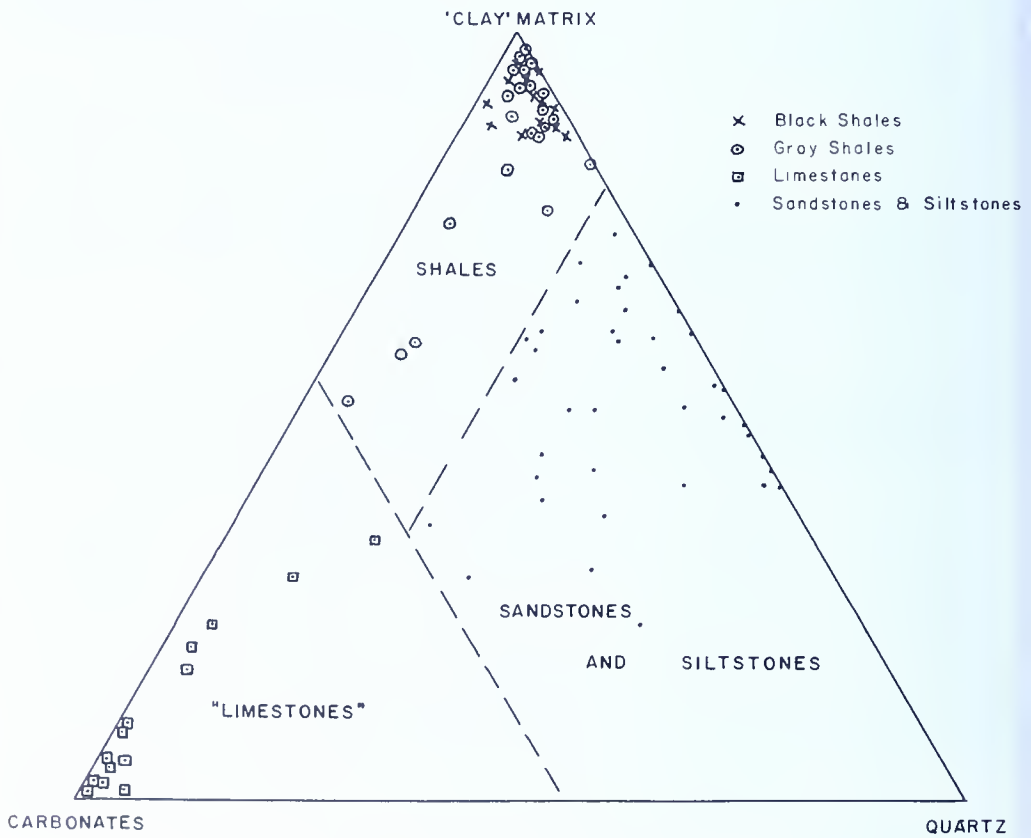

Figure 3. Petrographic Analyses of principal Lithologies

Size and sorting of quartz

Cumulative curves for detrital quartz in each of the rock types reveals an expected decrease in grain size from the Catskill lithofacies to the black and gray shales of the Portage lithofacies (see Figure 4). Surpris-

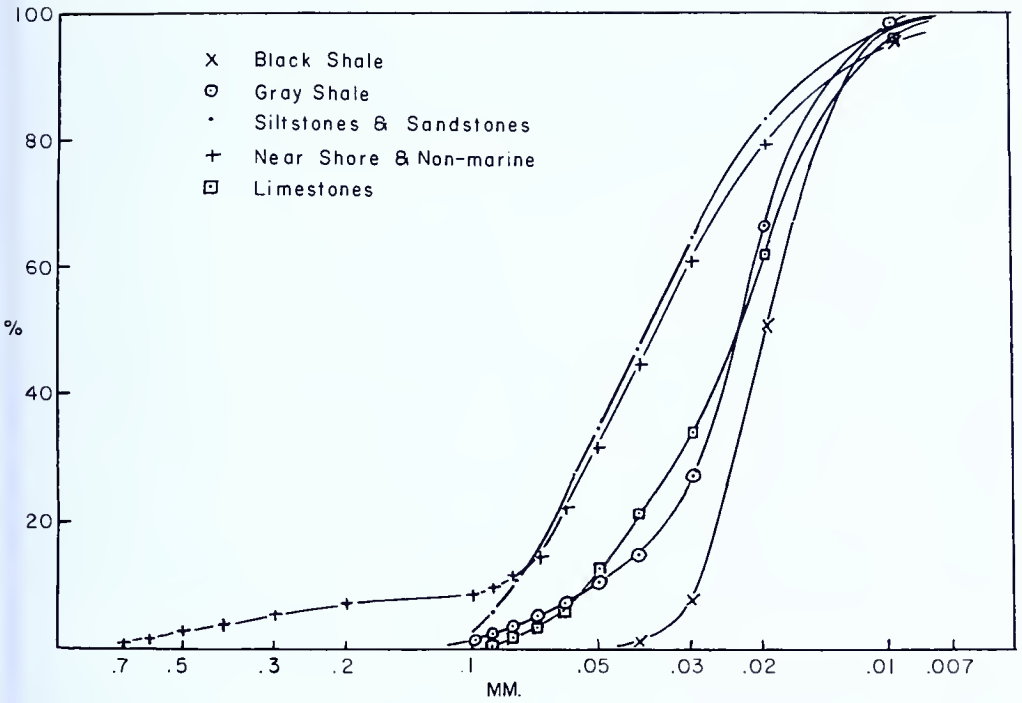

Figure 4. Cumulative curves for quartz

ing, however, is the similarity of the curve for near-shore deposits and the one for siltstones and sandstones deposited near the shelf edge. Except for the loss of the coarser fractions in the 0.1–0.01 mm. range, the distribution remains virtually unchanged. Average median diameters and sorting coefficients based upon 55 analyses are given below:

	So	*Dm*
Catskill Sediments	1.6	.037 mm.
Shelf-edge and Slope Sediments	1.58	.038 mm.
Gray shales	1.28	.024 mm.
Black shales	1.26	.020 mm.
Basin limestones	1.47	.024 mm.

Relations of quartz content and median diameter to paleoenvironments

Analyses of 66 thin sections were plotted relative to their position in the paleoenvironment. All were samples of pre-West Hill strata and the bulk represented the Tully-Moreland interval. In the basin-slope sediments, the percentage of quartz was found to increase toward the shelf edge (see Figure 5). The rate of increase changes abruptly about 20 miles west of the shelf edge. The sandstones on the shelf show some increase near the strand line but the rate is much lower. The median diameter of

the quartz shows a similar trend of the sands toward the Catskill facies. These patterns were best displayed by selecting the maximum values for each point. Although average values for all samples showed a similar trend, maximum values were used because the samples were not randomly selected in the field. The coarser beds tend to be sampled at the expense of the finer grained ones.

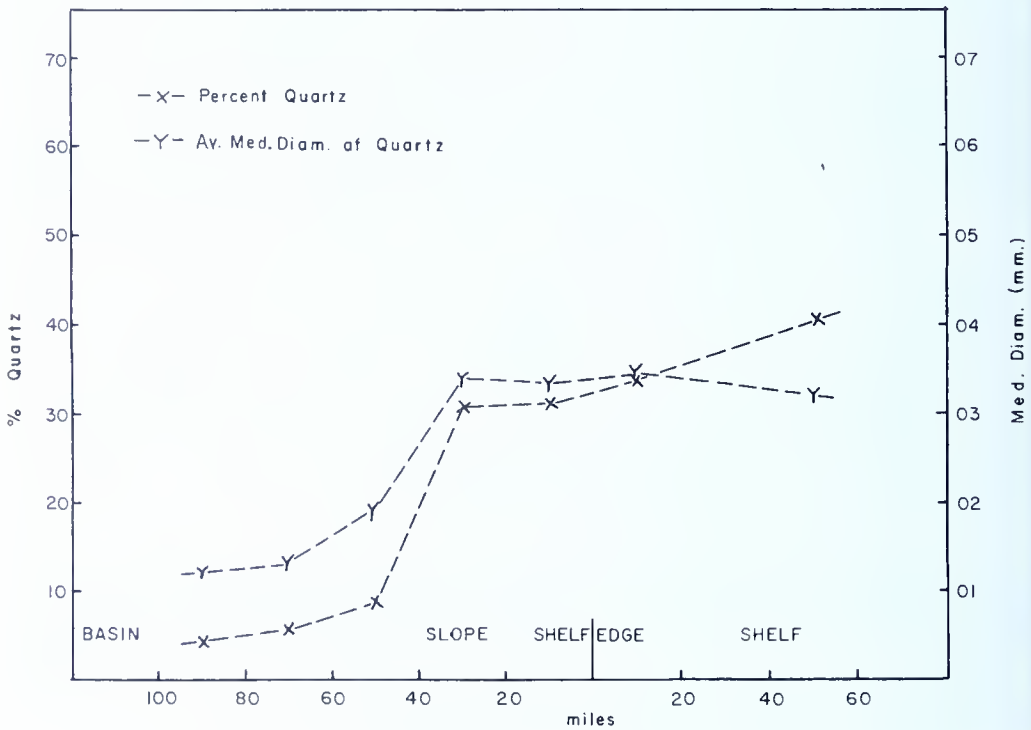

Figure 5. Relation of quartz content and size to paleoenvironments

Thickness of strata

If the position of a black shale is determined with respect to the underlying Tully limestone, an isopach map can be constructed. The contours on each trend N30°E and show an exponential increase toward the S60°E as described by Woodrow and Nugent (1963, p. 73). Where the black shale penetrates the Chemung lithofacies the thickening rate abruptly decreases. The point where this break occurs is interpreted as marking the edge of the shelf deposits when the black muds were deposited. The break in each succeeding Tully-black shale interval then accurately depicts the build-out of the delta complex.

Basin environments

The term basin as used here represents an area which existed in western New York during much of Late Devonian time. The basin is considered to

have been relatively deep, several hundred feet probably, and possibly several thousand feet. All evidence points to continued deposition of fine sediment, muds, and silts carried into the basin from easterly and southeasterly sources. Restricted vertical circulation is indicated by the virtual absence of current structures, the presence of black shales, and absence of large numbers of benthonic fossils and presence of relatively few pelagic forms.

Two theories exist which explain the origin of the siltstones in the Portage lithofacies. The first is a general increase in velocity of marine currents which would sweep coarser detritus into the basin; the second is the periodic emplacement of sediments by turbidity currents. If the first was the case, the siltstones in the basin would be expected to show better sorting than the associated shales and should be better sorted than the shelf sediments from which they were derived. Instead the quartz shows a lower sorting coefficient if compared with the values for the shales and a sorting coefficient close to that of the shelf sandstones. Most if not all of the silts must have been transported and emplaced with virtually no sorting. A turbidity current provides the obvious mechanism. The flute casts and flow markings on the base of the beds indicate a southeasterly source for the currents, a direction essentially normal to isopachs and trend of the shelf edge. Apparently no longitudinal currents operated in the basin to substantially deflect the course of the turbidity currents moving down the paleoslope. Some of the shales and thin siltstones show laminations (truncated in places) that may have been produced by slow-moving basin currents. If they existed at all they were incapable of moving large grains or bringing a substantial supply of oxygen to the sediment interface.

Slope environments

The slope deposits represent that portion of the Portage lithofacies marked by tongues of siltstone and fine-grained sandstone. Some examples are the Sherburne (Cayuga and Keuka Valleys), Rock Stream, Millport (Ithaca quadrangle), Beers Hill (Watkins quadrangle), and the Gardeau (north of Corning). The beds are thicker and coarser grained than the basin deposits, marked by numerous flute and groove casts, and show convolute bedding. The tongues appear to increase in width (measured normal to the shelf edge and parallel to the flute casts) from the Sherburne to the Gardeau. This change is interpreted as evidence that the slope increased in width as a result of the deepening of the basin. Increased differentiation of the basin and shelf faunas lends support to this hypothesis.

Although the ultimate source of the sediments was a terrigeneous one, the turbidity currents are thought to have been derived from the edges of the shelf. Evidence for this is the general lack of fossils that characterize

the beds of the shelf proper as well as the scarcity of coarse sand present in some of the inner shelf deposits. The percentage of quartz in the slope deposits shows little change for a distance of more than 30 miles from the shelf edge and is best explained if the coarsest beds are emplaced by turbidity currents (see Figure 5). Some of the thin limestones in the slope and basin were believed derived from coquinites on the shelf.

If the turbidity currents moved from the edge of the shelf, there should be evidence of their points of origin. It is suggested that some of the small faults and previously unexplained folds may have been the sites. These structures have been dutifully noted by many geologists mapping the Upper Devonian. Bradley and Pepper (1938, p. 38) pointed out:

> "Many of the features of these beds indicate plainly that they were deformed while still wet and plastic. The authors conclude, therefore, that the faults which these deformed zones accompany were active during that part of the Upper Devonian time when these beds had just been deposited and were then only shallowly buried on the sea floor."

Previously, the orientation of such structures had been related to tectonic patterns only. Instead the orientation may have been governed by the paleoslope.

A second possible source or triggering mechanism may have been the extrusion of water from the muds on the outer part of the shelf. This thixotropic response of the sediment may have produced the "flow rolls" or slump structures and simultaneously triggered the currents.

Shelf environments

The Otselic, Cincinnatus, West Danby (east of Dryden), Rhinestreet (east of Waverly), Gardeau (east of Elmira), Wiscoy, and Perrysburg (Corning quadrangle) are identified as shelf deposits. Similarities of their faunas are discussed by Greiner (1957), McAlester (1962), and others. The strata are referred to as shelf deposits because of their broad lateral extent, presence of coquinitic limestones, cross-bedded sandstones, and other evidences of current and wave action. In places crinoid fragments are the major rock constituent. Nearby only shells of a narrow size-range may be found. Cup corals may be found. Considering the shale tongues (now dark gray) as time planes the shelf width may be estimated and found to vary between 25 and 45 miles. If the shelf was approximately 600 feet deep at its edge the paleoslope would range from 13 to 24 feet. All of these values compare favorably with those of the Atlantic Shelf.

If we assume that general subsidence took place in western and central New York during the Upper Devonian, with 40 percent reduction in sediment thickness due to compaction and only 300 feet of water overlying the shelf edge, the depth of water in the vicinity of Batavia would have been 1700 feet, 1000 feet in the Watkins quadrangle and less than 300 feet in the Dryden quadrangle during Middlesex time. Slope calculations are

32 feet per mile between Dryden and Watkins Glen, 10 feet per mile between Watkins Glen and Batavia (basin), and less than 10 feet per mile east of Dryden to the strand line. Although differential subsidence probably occurred, the relative difference in the paleoslope values are considered to be real and the concept of shelf, slope, and basin environments justified by all the evidence at hand.

Shoreline and terrestrial environments

The sediments considered here are collectively summarized by the term "Catskill" lithofacies and interpreted as indicating strandline and non-marine environments. They are characteristically quartz-pebble and shale-pebble conglomerates, dark-gray, red and green shales, and greenish-gray and red sandstones. Although coquinites have been found associated with these lithologies, each example has been found to be stratigraphically close to the Chemung lithofacies so that such occurrences are interpreted as strand line deposits and in no way invalidate the supposition of a non-marine origin for the bulk of the Catskill.

The sediments are fairly uniform in thickness. Channels do occur and may be filled with conglomerate but their relief is seldom more than 20 feet. Such evidence indicates that the nearshore portions of the delta at least were relatively low in elevation. Large cobbles and boulders are rare so that if a high mountainous area were supplying sediment it did not exist west of the Hudson River. The streams that poured sediment into the marine portion of the delta are pictured as having a low gradient with a velocity sufficient to move sand-sized particles. Upon occasion this velocity increased sufficiently to move pebbles and erode previously deposited sediment, carrying some as fragments of soft red and greenish-gray mud that were redeposited with the sands. This portion of the delta was characterized by lagoons, tidal flats, low marshes, and meandering streams where sedimentary accumulation was close to subsidence rate.

Stages in the cyclical development of the delta complex

Stage 1. Subsidence of the geosyncline, uplift of source area and barring of the basin. Lagoons developed as the coastal area was flooded. Dark-gray to black muds characterize the shelf area, slope, and basin. Benthonic fauna are restricted in character and confined to areas near the shore.

Stage 2. Adjustment of the Shelf. Muds, sands and gravels are deposited in the lagoons and on the shelf, gradually building out toward the edge of the older shelf. A large volume of sediment is derived from the source area. The strand line moves out with the sands and the depth of water de-

creases. The benthonic fauna spreads out geographically and is less restricted in character.

Stage 3. Extension of the Shelf. Sands and silt build-up reaches the site of older shelf-edge and steppens the upper reaches of the slope. These sediments slump and form turbidity currents and shelf edge is extended. Weak basin-currents supply some oxygen, resulting in gray muds and an increased population of vagrant benthonic forms.

Stage 4. Stability. The rate of sediment supply is reduced. Shelf waters are less muddy, sands are better sorted (protoquartzites) and limestones may be formed on the shelf. Fewer turbidites are formed because of slope adjustment.

Stages 1 and 2 are present in all cycles, 3 in most and 4 in but two places. Constant adjustments occurred producing irregularities in the pattern. Subsidence occurred not only during Stage 1 but was probably continuous; its major effect occurred at Stage 1. Several faunal zones marked by *Cyrtospirifer chemungensis* were mapped across the area. Each zone began in the east just above a dark gray shale tongue but ended just below the next overlying dark shale many miles to the west. The repetition of this pattern is cited as evidence that the fauna migrated westward as the environmental conditions improved.

Stage 4 existed briefly during Hamilton time when the Portland Point limestone was deposited, again with the Tully limestone and finally during deposition of part of the Wiscoy. In each case protoquartzites appear to be the eastward equivalents of shelf limestones.

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Catskill and the Acadian Discontinuity

ABSTRACT

Interregional stratigraphic integration and synthesis of Devonian and Mississippian extends the Acadian Discontinuity, as interpreted by King (1955) in southeastern United States, to near Pan-continental occurrence, and indicates basal Catskill as its most probable position in the Pennsylvania-New York region. This and the similarity of the differentials involving the Catskill and Hamilton-Tully-Genesee-Portage-Chemung succession to sequence boundary relations elsewhere, indicate that the Catskill truncates these formations rather than being intertongued with them, as generally interpreted. In addition, faunal patterns suggest such a discontinuity. All these, together with the fact that the interpreted intertonguing appears never to have been demonstrated, indicate that the Acadian Discontinuity is present in a sub-Catskill position in Pennsylvania and New York. The patterns also indicate that the Catskill is in part of Mississippian age.

INTRODUCTION

American Geologists generally are aware of the voluminous literature in which many slightly to moderately variant interpretations (and their innumerable "appropriate nomenclatural revisions) have been presented during the past century in explanation of the ever-variant and commonly anomalous relationships between the "Catskill" (which itself is somewhat variously conceived) and the other stratal entities with which it is associated in the New York-Pennsylvania region. Equally evident is the basic theme to which the many minor interpretational variations "relate"; *i.e.*, the general notion that the Catskill is a "facies" of *all* Devonian stratigraphic units with which it *presently* has contact. In retrospect, the evolution of this notion is not surprising in view of the paucity of good exposures; the undetectability of most Paleozoic discordances at the local outcrop scale; the long-standing interpretation (assumption?) that the Devonian record of this region is "essentially complete"; and perhaps above all, the common but fallacious acceptance of the presently preserved record as being essentially synonymous with original deposition. In fact, this interpreted relationship between the Catskill and its various "correlatives" has become in recent years one of the most frequently cited "textbook types" to exemplify extremely marked facies variation within relatively short lateral distances, and involving rocks representing a fairly long interval of geologic time.

On critical examination, however, the generally accepted interpretation (or its slight variants) that the Catskill "facies" spans the entire interval from early Middle Devonian (Hamilton, or perhaps Marcellus) to within early Mississippian time, reveals its contingency upon conditions which appear to have remained undemonstrated. This is not to contend that the aspect of the succession which is most commonly regarded as Catskill bears no significant facies relation to strata representing the same depositional interval further westerly; but merely that an *appreciable part* of these universally accepted and often-cited "Middle and Upper Devonian" facies patterns may have no basis beyond speculation. To be more specific, the belief that the Catskill "facies" (lithosome) is intertongued with the strata comprising the Hamilton, Tully, Genesee, and Portage Formations, together with at least the lower part of the succession variously regarded as "Chemung," is without adequate basis in the form of detailed description of field relations.

The mere fact of this inadequacy, of course, does not demonstrate that such intertonguing is nonexistent; it indicates only that in terms of published data the interpretation that these strata are not intertongued is at least as justified as the interpretation that they are intertongued. The significant implication here is that if the unfounded prevailing notion is invalid, the Catskill and its temporal correlatives must lie wholly, and apparently unconformably, above the above-listed "Middle and lower-Upper Devonian" strata. And if this is true, it has paramount implications which reach far beyond this relatively minor part of North America. The consequent conditions of first-order importance are at least two-fold: first, the recognition of the Acadian discontinuity in the New York-Pennsylvania region, as in most other parts of the continent where preservational patterns permit; and second, the implications of this discontinuity with regard to the "established" New York Devonian "standard" section.

The writer's qualifications to express judgment on the Paleozoic problems of this region are open to serious question. His visits to the field in this region have been few and brief; and least of all has his limited examination of critical relationships involved the particular segments of the record under consideration. However, he justifies (or rationalizes) his acceptance of the invitation to submit this "contribution" to the symposium on three counts: first, he has had the temerity to express some of these views elsewhere (Wheeler, 1963a); second, those responsible for the invitation may be guilty of even poorer judgment; and third (and hopefully the most justifiable) he is confident that interregional stratigraphic integration and synthesis repeatedly provides valid bases for both "predicting" previously uninterpreted patterns, and reinterpreting or at least questioning many "established" relationships.

The reader should bear in mind that the writer's position with regard to these questions and their solution is not categorical. He is neither able to

positively deny the traditional interpretations nor to conclusively demonstrate his own. But it should also be borne in mind that the interpretations regarded herein as more probable are not the product of caprice or whimsy. Only after about six years of intermittent concern were the writer's prejudices sufficiently softened to allow the "outrageous" thought that the Acadian "break" may be sub-Catskill.

In the interest of brevity, definition of the less frequently employed kinds of stratigraphic concepts and entities required in interregional integration and synthesis are not repeated here. Let it suffice to point out that in addition to the more familiar kinds of physical, bio- and time-stratigraphic units, little can be accomplished or adequately envisaged without the concepts of such units as *sequence, holostrome, lacuna, erosional vacuity,* and *hiatus,* together with the dimensional frameworks in which they are conceived. These are briefly defined or reviewed by Wheeler (1958a and 1959b) and most are exemplified by Wheeler (1963a).

The interval under present consideration lies entirely within the "Kaskaskia Sequence" of Sloss (1963) which comprises most Devonian and Mississippian strata of the cratonic interior and some of the more bordering areas in North America. By the writer's interpretation, however, the "Kaskaskia" consists of two independent sequences, Piankasha and Tamaroa, which are separated by the Acadian discontinuity (Wheeler, 1963a). At the very outset, therefore, it will be seen that the writer's position is controversial—not alone in the New York-Pennsylvania region, but over the continent as a whole. With this shaky introduction, these framework patterns are discussed in the belief that they will bring probabilities to bear on the New York-Pennsylvania patterns.

PIANKASHA SEQUENCE

The validity of the writer's interpretation of Catskill correlatives, and of its role in the late Paleozoic history of North America, depends in a large measure on the existence of the Piankasha Sequence (Wheeler, 1963a) as an essentially pan-continental, unconformity-bounded, intra-Devonian succession; or at least it depends on the interregional extent of the unconformable separation of a succession which is largely of Middle Devonian age, from an overlying sequence which is largely of Mississippian age, but whose basal strata may vary from latest Devonian to very early Mississippian. This is not the place to argue the separation of the Piankasha from the preceding, Siluro-Devonian Tippecanoe Sequence (Sloss, 1963) or from the upper Tippecanoe equivalent in eastern America, the Tutelo Sequence (Wheeler, 1963a), for none of the formations (Oriskany and older) involved in that earlier intra-Devonian (Wallbridge) discontinuity are implicated in the Catskill problem. It will, therefore, suffice here to point out that the erosionally truncated remnants of a pan-

continentally deposited, Middle to perhaps early-Late Devonian succession repeatedly but intermittently occur beneath a sequence which begins with latest Devonian or earliest Mississippian beds (Fig. 1).

Disregarding the evaporites in its upper part in the Montana-Dakota region and northward in Canada, the Piankasha Sequence is largely detrital in the East, and overwhelmingly carbonate in the West. In the Pennsylvania-New York region, for example, this succession is characterized by the Oriskany, Onondaga, Marcellus, Hamilton, Tully, Genesee, and Portage Formations, and part, at least, of the "Chemung." Of these, only the relatively thin Onondaga and Tully are non-detrital. Progressively from the base upward and from east to west, this detrital lithosome clearly intertongues with a carbonate lithosome which carries all the way to the Pacific Coast (Wheeler, 1963a). On the accompanying paleogeologic cross-section (Fig. 1) in Missouri, for example, the carbonate lithosome (with its relatively local Dutch Creek Sandstone base) comprises the Grand Tower, Wittenburg and Callaway Limestones; while the overlying Snyder Creek Shale apparently represents one of the most westerly preserved remnants of the easterly derived detrital lithosome. Conversely, the Onondaga and Tully limestones are segments of easterly extending tongues of the carbonate lithosome. In the interest of brevity and the avoidance of unnecessary repetition, the reader is referred to the more detailed description of this widespread, and major intra-Devonian unit (Wheeler, 1963a). Figure 1, herein, exemplifies this Piankasha Sequence in parts of the Midwest and East.

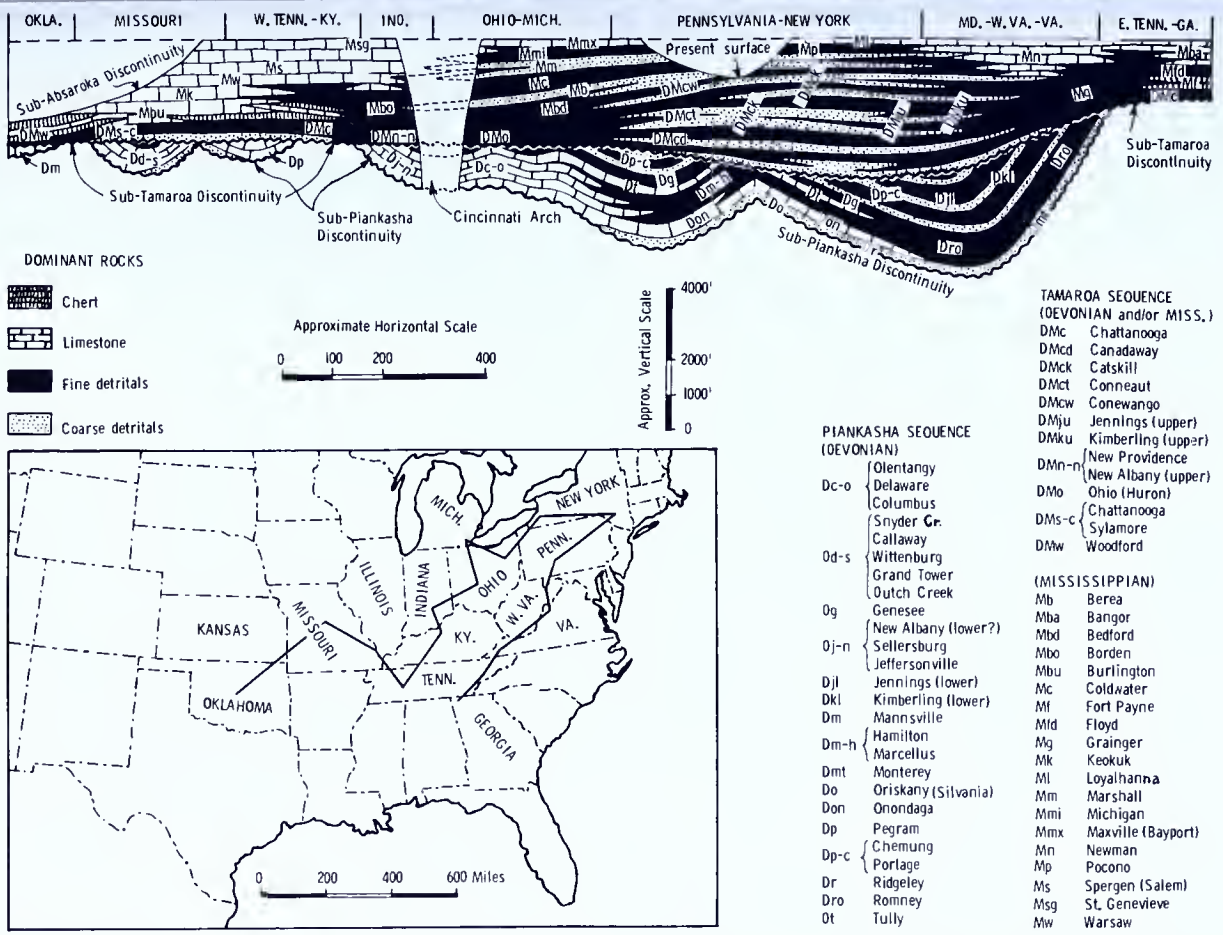
ACADIAN DISCONTINUITY AND THE TAMAROA SEQUENCE

Schuchert and Dunbar (1933) designated the Acadian Orogeny, although they envisaged no manifestation of it in the form of a discontinuity. These authors stated:

> "The vast wedge of detrital sediments comprised in the Catskill Delta, like a similar one in Quebec (Gaspe) was obviously derived from rising highlands that lay to the east. The progressive change in Middle to Upper Devonian sediments of New York and Pennsylvania shows likewise, that the uplift began in the middle of the period and reached its climax at the close."

Although Schuchert and Dunbar, in accordance with the accepted notion at the time, assumed that the climax of the orogeny must coincide with the "close" of the Devonian, and although they saw no significant discontinuity as a consequence of the tectonism, they nevertheless bracketed an important diastrophic episode within the interval between a position within Middle Devonian and the beginning of the Mississippian.

Because the regional unconformity which King (1955) observed beneath the Chattanooga and its correlatives "from the front of the Appalachians westward to Oklahoma" falls within the interval bracketed by Schuchert



PIANKASHA SEQUENCE (DEVONIAN)

Dc-o	Olentangy, Delaware, Columbus
Od-s	Snyder Cr., Callaway, Wittenburg, Grand Tower, Dutch Creek
Og	Genesee
Oj-n	New Albany (lower?), Sellersburg, Jeffersonville
Djl	Jennings (lower)
Dkl	Kimberling (lower)
Dm	Mannsville
Dm-h	Hamilton, Marcellus
Dmt	Monterey
Do	Oriskany (Silvania)
Don	Onondaga
Dp	Pegram
Dp-c	Chemung, Portage
Dr	Ridgeley
Dro	Romney
Ot	Tully

TAMAROA SEQUENCE (DEVONIAN and/or MISS.)

DMc	Chattanooga
DMcd	Canadaway
DMck	Catskill
DMct	Conneaut
DMcw	Conewango
DMju	Jennings (upper)
DMku	Kimberling (upper)
DMn-n	New Providence, New Albany (upper)
DMo	Ohio (Huron)
DMs-c	Chattanooga, Sylamore
DMw	Woodford

(MISSISSIPPIAN)

Mb	Berea
Mba	Bangor
Mbd	Bedford
Mbo	Borden
Mbu	Burlington
Mc	Coldwater
Mf	Fort Payne
Mfd	Floyd
Mg	Grainger
Mk	Keokuk
Ml	Loyalhanna
Mm	Marshall
Mmi	Michigan
Mmx	Maxville (Bayport)
Mn	Newman
Mp	Pocono
Ms	Spergen (Salem)
Msg	St. Genevieve
Mw	Warsaw

Figure 1. Paleagealagic crass-sectian at appraximate end af Meramecian, shawing lithasamal patterns af the pre-Chester part af the Tamaraa (Devanian-Mississippian) Sequence and preserved parts of the Piankasha (intra-Devanian) Sequence.

and Dunbar, because King appropriately attributed that break to the Acadian, and because King's regional discontinuity coincides with the one which the writer interprets to be of vastly greater extent in North America, the name Acadian is deemed most appropriate for this sequence-bounding unconformity from Georgia through central Texas and New Mexico on the south to the Arctic on the north, and from Maritime Canada through the Appalachians on the east to within the Cordilleran Geosyncline on the west. King, however, was the first to see its effects as interregionally extensive. In relating the Appalachian-to-Oklahoma break to the Acadian, he stated: "The approximate correspondence of this epoch of warping, erosion, and transgression to the climax of the Acadian orogeny is of interest, the epeirogenic movements affecting at least a quarter of the continent, the orogenic with a proved extent only in New England and the Maritime Provinces." In fact, except for the contrary traditional interpretation in Pennsylvania-New York and some neighboring areas, in all parts of North America where latest Devonian and/or earliest Mississippian strata are known to be present, a demonstrable successional break occurs beneath them.

The preceding statement does not imply that at the base of all exposures of such "Devono-Mississippian" strata in any exposure, one invariably "sees" an obvious unconformity. It means that these beds are either resting on rocks which are vastly older or are resting with demonstrable *differential* on *various* somewhat older rocks within the area. In this sense, unconformities of the nature and order of magnitude of those designated as sequence boundaries are demonstrated statistically, even though they may not be "seen" at many localities (Wheeler, 1963a and 1963b). It is on the basis of this approach that the sub-Tamaroa or Acadian Discontinuity is clearly demonstrable in at least Idaho, Nevada, Montana, Wyoming, Utah, Arizona, Colorado, New Mexico, North Dakota, Kansas, Oklahoma, Texas, Iowa, Missouri, Arkansas, Illinois, Kentucky, Tennessee, Mississippi, Alabama, Georgia, and Maine, not to mention a number of Canadian Provinces. Moreover, there is strong evidence for its presence in nearly all other states where strata most logically regarded as basal Tamaroa are presently preserved, including Pennsylvania and New York.

Without again reviewing the pattern of the continent as a whole, the accompanying paleogeologic cross-section (Fig. 1) illustrates the writer's present interpretation of these patterns from the Oklahoma, Kansas, Missouri, Illinois, western Tennessee and Kentucky region, where the Acadian discontinuity is clearly evident; through the controversial and anomalous patterns of Indiana, Ohio, and southern Michigan; thence through New York, Pennsylvania, Maryland, West Virginia, Virginia, and easternmost Tennessee, where this unconformity appears never to have been envisaged previously; to the southernmost Appalachians, where it is again obvious.

That part of the section from central Oklahoma through Kentucky needs little discussion. As stated above, King (1955) has noted the break through the southerly part of this region. In addition, Shannon (1962) has properly placed it at the sub-Woodford position in most of his Oklahoma sections. Otherwise the basal Tamaroa units (Chattanooga, Woodford, Sylamore, Bushberg, Hardin, etc.) rest on subcrops variously laid bare by truncation from intra-Piankasha (mid-Devonian), through Tippecanoe (mid-Ordovician to Lower Devonian), to upper Sauk (Cambrian to Lower Ordovician).

From Indiana to New York, however, the Acadian Unconformity is not such an obvious feature. The problem is aggravated by the fact that in parts, at least, of Indiana, Ohio, and southern Michigan, the Chattanooga and its "black shale" correlatives understandably lose the coarse sandy and/or calcareous base in areas where the subcrop is Piankasha "black shale." As a consequence, the unconformity in many areas appears to be "lost" within the shale. This, in fact, is the crux of the long-standing "black shale problem" which has given rise to seemingly irreconcilable stratigraphic anomalies from eastern Tennessee to Michigan and westward to the Illinois Basin. The writer currently believes that this problem is basically simple; *i.e.,* that as a consequence of the universally present Acadian discontinuity, the basal Tamaroa shales (Chattanooga, Ohio, Huron, upper Antrim, upper Romney, and most of the New Albany, *etc.*) alternately lie on post-Tully-Delaware-Traverse-Sellersburg shales, and various units beneath those mid-Devonian shales. Huddle (1934), for example, reported Genesee conodonts from the lower New Albany in Indiana. In Ohio, Stauffer (1916) and Lamborn (1927 and 1929) interpreted a marked differential beneath the Ohio-Huron. In his recent review of the "black shale problem" in Ohio, Hoover (1960) presented extensive faunal lists. By regrouping the taxons in accordance with their position relative to the base of the Huron-Ohio, Wheeler (1963a) showed that only a small percentage of the species listed occur both below and above this interpreted position of the Acadian break. For example, among the 233 conodont species listed, only five occur both below and above the base of the Huron-Ohio; and only three of 42 genera cross this stratigraphic datum.

Therefore, although with somewhat less truncational differential than in the region from Oklahoma to Kentucky, the sub-Tamaroa discontinuity appears to be no less real in the eastern Midwest.

In spite of the virtually universal belief that the Devonian of New York and Pennsylvania is essentially complete, there is nevertheless appreciable evidence for the Acadian discontinuity there, as well. In that region, however, along with the easterly changes of facies, the name (though not the basic nature) of the problem also changes. There it has not been the

"black shale problem," but the "Catskill problem." Although many, if not most, believe that this problem has been solved in recent decades, the generally accepted interpretation that the "Catskill facies" or lithosome is intertongued with the entire more westerly succession from at least as low as the Hamilton to at least as high as the Conewango, to say the least, is open to serious question.

In brief review, from 1840 to 1887 the Catskill was regarded as following the underlying marine Devonian in normal depositional succession. Williams (1887) was the first to interpret that the Catskill is intertongued with the Middle Devonian marine strata, and that its first deposition in eastern New York commenced during Hamilton time, but he demonstrated neither. Except for minor variations in their patterns, all subsequent investigators have accepted this unsubstantiated interpretation that the base of the Catskill is markedly temporally variant, and that it is a "facies," not only of the post-Chemung latest Devonian marine strata to the west, but of most of the Middle Devonian, as well. For example Chadwick (1933) stated that the Catskill "interfingers with marine sediments containing Portage and Hamilton fossils," and he cited Cooper (1933) for verification. Cooper, however, did not indicate that the continental strata are actually *interbedded* with the shales containing Hamilton fossils; he merely pointed out the Hamilton position at which the red beds "appear" or at which the Hamilton "has passed over to continental beds."

The name "Chemung Group" commonly has been applied to a diverse succession of post-Portage formations in western New York and Pennsylvani in which, at varying positions above its base, sediments of the Catskill type first appear. Thus in the areas of its occurrence, the lower "Chemung" and its faunas are pre-Catskill (at least locally), and the upper part and its faunas, by virtue of repeatedly described interbedding, seem clearly contemporaneous with at least some of the Catskill. Seemingly of obvious significance in this regard, is the study by Chadwick (1935) in which he stated:

> "The fossiliferous strata formerly called 'Chemung' on the Genesee River are now known to differ in the presence of 130 species not found in the true Chemung strata below, and in the absence of 240 [true Chemung] species . . . . . while there are less than 100 species in common. These ["pseudo-Chemung"] beds with the *Athyris Angelica*" fauna constitute the Canadaway group, which traced eastward goes wholly above type Chemung."

It is especially noteworthy that the Canadaway or "pseudo-Chemung" of Chadwick (not the "true Chemung") contains Catskill-type intercallations.

In view of the implications of these items extracted from the voluminous literature on these relationships, it seems implausible that the existing interpretation has stood unquestioned for three-quarters of a century, and that no one has given serious consideration to the obvious possibility (if not the probability) that the nonmarine lithosome represented by the Cats-

kill in eastern New York and Pennsylvania is essentially contemporaneous with the marine strata to the west with which it is demonstrably intertongued (Canadaway and above), and that both are unconformable upon the truncated Hamilton, Tully, Genesee, Portage and "true Chemung." In further support of the likelyhood, the writer has learned of an investigator who recently abandoned a detailed study of the "intertonguing" of the Catskill and the Middle Devonian formations because he could find no supporting evidence!

The foregoing provides a strong indication that the long-presumed complete Late Devonian of the New York-Pennsylvania region is agape with a major lacuna, and that its sub-Catskill unconformity is actually the widespread Acadian break. In any event, in the light of the presently available interregional, regional, and local relations, the least to be said is that this part of the New York-Pennsylvania Devonian, together with the apparently involved Mississippian, appears to be long overdue for critical physical and biostratigraphic review. In the meantime, the writer believes that the evidence for the Acadian Unconformity and its accompanying sub-Tamaroa erosional differentials appreciably outweighs that upon which the "established" interpretation has been based.

If the actual patterns should prove to be similar to these that are anticipated in the light of the interregional approach, significant biostratigraphic considerations are at stake. If the Late Devonian of this region is shown to be agape, radical readjustments in the traditional biostratigraphic standards (and the concepts with which they are applied) will be in order. In this regard, it appears possible that the faunal distinctions between the Chemung and Canadaway may be greater than Chadwick's (1933 and 1935) lists, just as they are in Ohio between the Olentangy and Ohio-Huron. For example, Chadwick listed *Cyrtospirifer* from both the upper Chemung and Canadaway; while the writer is unaware of the occurrence of this genus below the Acadian Discontinuity elsewhere in North America. Is it possible that he mislocated the contact relative to this and perhaps associated fossils? If so, this genus and possibly others may be more restricted than Chadwick indicated.

The top of the paleogeologic section (Fig. 1) accepts the common interpretation that the Loyalhanna limestone of Pennsylvania is correlative with Maxville, Bayport, St. Genevieve, Greenbrier, upper Newman, and upper Bangor. It follows, and makes eminently good sense otherwise, that the underlying Pocono, Michigan and the evaporite-bearing St. Louis are also essentially correlative. And if these correlations are true, it seems inevitable that much of the Catskill (at least as preserved in much of Pennsylvania and southwestward) is of Mississippian rather than late Devonian age as generally regarded.

Southwestward from Pennsylvania to southwestern Virginia, the separa-

tion of the Catskill element from the remainder of the Jennings and Kimberling presently appears to be the most questionable link in the entire chain, although further on, in eastern Tennessee and beyond to Georgia and Alabama, the unconformity beneath the basal Tamaroa (Chattanooga) is obvious. Nevertheless, since the Oriskany, Marcellus, Hamilton, and Genesee elements of the Piankasha Sequence carry through this doubtful region (as Ridgely-Monterey and Romney) until truncated by the unconformity, the implication, from this interregional viewpoint, is that the Chemung equivalent in the Jennings and Kimberling are also truncated.

On the opposite side of the Pennsylvania-New York region from the patterns thus far considered, no one has doubted the tectonic effects of the Acadian Orogeny. Moreover, the distinctly Catskill-like, Late Devonian Perry appears to represent the basal Tamaroa in Maine. In fact, Bastin (1914) correlated it with the "Chemung" and Catskill. In addition, the Pondville-Wamsutta of Massashusetts and Rhode Island are most logically regarded as Catskill correlatives.

Thus as the Pennsylvania-New York region is approached from various directions, on the basis of a general interregional integration of Devonian and Mississippian stratigraphic patterns, and in the light of the several significantly anomalous relationships within this region, the statistical probabilities appear to weigh heavily in favor of interpretations that, except for differences in the character and details of rock relationships, the "Catskill problem" is of precisely the same nature as the "black shale problem" to the west; that the Acadian Unconformity is present in a sub-Catskill position; that the basal Catskill is very late Devonian (nowhere Middle Devonian) in age; and that some, if not much, of the Catskill is of Mississippian age. Moreover, these probabilities also indicate that the burden of proof is heavier for those who hold the traditional view.

Finally, it appears evident that the conclusive demonstration of these or other stratigraphic patterns is not to be found in the Pennsylvania-New York region alone, but in adequately integrated studies throughout much of eastern North America.

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Devonian and Mississippian Correlations in Part of North-Central Pennsylvania—a Report of Progress[1]

ABSTRACT

During the first 2½ years of this study 120 sections were measured involving Upper Devonian and Mississippian rocks along Pine Creek Valley in Tioga and Lycoming Counties, Pa. The Cedar Run 7½-minute quadrangle has been mapped, and tentative correlations have been extended about 28 miles south to the vicinity of Jersey Shore.

Although formal rock-stratigraphic names have been assigned to these strata by others working in north-central Pennsylvania, I have used informal nomenclature for two reasons: 1) The type localities of the previously used stratigraphic units are far from the study area. 2) The units have not been traced with certainty from their type localities in other parts of Pennsylvania and New York into the study area.

I recognize the following sequence of rocks in the Cedar Run quadrangle:

1) Sandstone and conglomerate of Pennsylvanian age (basal 65 feet exposed).
2) Sandstone and conglomerate of Mississippian age (40–60 feet): includes the conglomeratic Burgoon (?) Sandstone of Ebright (1952) at base, and locally the Mauch Chunk Series of Ebright (1952) at the top.
3) Upper sandstone sequence (175–240 feet): contains several units of red rock, including the Patton Red Shale of Ebright (1952) near the top.
4) Lower sandstone sequence (350–490 feet): includes several units of red rock in upper two-thirds, the conglomerate at Cedar Run at the top, and the Oswayo Formation of Ebright (1952) in the lower part.
5) Red-bed sequence (1407 feet exposed, basal 70 feet below drainage): The Catskill Red Beds of Ebright (1952).

The conglomerate at Cedar Run is an excellent marker bed because it is thin, lithologically distinctive, and laterally persistent over at least 800 square miles. Its top is provisionally considered to mark the boundary between the Devonian and Mississippian Systems.

It is tentatively concluded that southward from the Cedar Run quadrangle: 1) The top of the red-bed sequence rises to displace much of the lower sandstone sequence; 2) beds of red rock in the lower and upper sandstone sequences thicken; 3) the conglomerate at Cedar Run is well developed at the Allegheny Topographic Front; 4) the sandstone and conglomerate of Mississippian age appears to thicken; 5) a thin red mudrock in the top of the Mississippian System—possibly the Mauch Chunk Shale—thickens.

INTRODUCTION

The present project, started in the summer of 1961 with the cooperation of The Pennsylvania Geological Survey, is concerned primarily with the

[1]Publication authorized by the Director, U. S. Geological Survey.

stratigraphy, structure, and mineral resources of the late Paleozoic rocks in part of north-central Pennsylvania. The project area (Fig. 1) occupies a north-south belt that extends along Pine Creek from the Appalachian Plateau province southward into the Ridge and Valley province.

To date about 120 sections have been measured in the process of completely mapping one 7½-minute quadrangle (Colton, 1963) and of partially mapping three others. Other sections have been measured west of the study area to tie in with earlier studies by members of the Pennsylvania Geological Survey (Ebright and others, 1949; Ebright and Ingham, 1951; Ebright, 1952; Bolger and Gouse, 1953), and also along parts of Pine Creek where quadrangles are not being mapped completely.

That part of the project area within the Appalachian Plateau is underlain by very gently folded upper Upper Devonian and Mississippian rocks

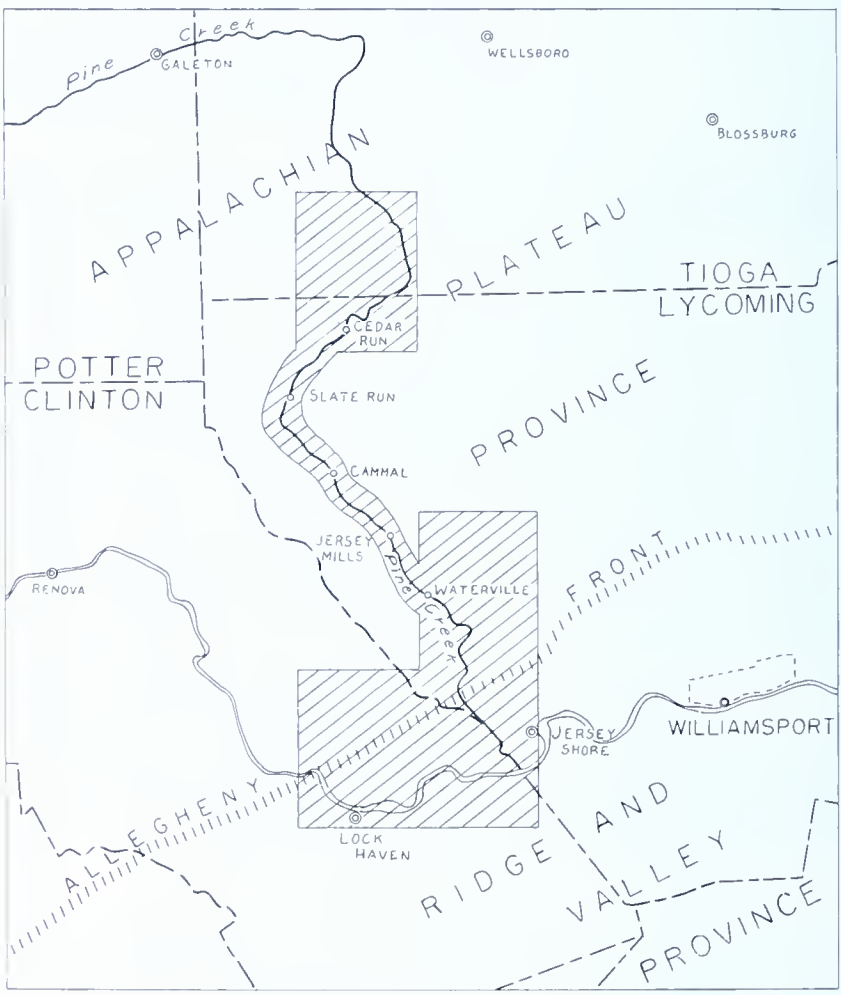

Figure 1. Map showing location of project area (cross-hatched), and places and features mentioned in text.

of continental origin. The stratigraphic sequence and correlation of these rocks will be the topic of this paper. Lower Pennsylvanian rocks cap some parts of the area, but they are poorly exposed and have not yet been studied in detail. The southern part of the project area lies within the more intensely deformed Ridge and Valley province, and is underlain by rocks of marine origin ranging from middle Late Devonian to Middle Ordovician in age. These older rocks will not be discussed further in this paper.

NOMENCLATURE

There has been little recent work in this part of north-central Pennsylvania. Since the county reports of Lesley and others (1878) and Sherwood and Platt (1880) only one map had been published (Ebright, 1952) covering part of the project area until the present investigation began. Reconnaissance work by Willard (1939) covered some areas to the north and west, and one section was measured by Willard (1939, p. 326–328, Fig. 91, 93) near the mouth of Pine Creek.

The scarcity of recent work in the area was partial justification, I thought, for using informal stratigraphic names during the early phase of this investigation. Further justification stems from the fact that previously named formal rock units which might apply to the study area have not been traced in detail from their type areas in other parts of Pennsylvania and in New York (Fig. 2) into the north-central part of the State.

Additional detailed mapping within the study area and reconnaissance work outside of the area are necessary. After further work a formal system of nomenclature can be applied with more certainty that the names are appropriate than is possible at present. Possibly some of the articles in this Symposium Volume will contribute to a better understanding of regional correlations of the Upper Devonian and Mississippian strata, and hence to a better understanding of the sequence in the study area.

ROCK SEQUENCE IN THE CEDAR RUN QUADRANGLE

The northernmost quadrangle in the study area, the Cedar Run 7½-minute quadrangle, has been mapped in detail (Colton, 1963). Fifty-two sections were measured by steel tape and surveying altimeter on the noses of mountains in the quadrangle; in addition the longer exposures along the stream valleys were measured by plane table and alidade. Graphic columnar sections were plotted for each traverse after compensating for the attitude of the strata to obtain true stratigraphic thicknesses. Correlations were made by comparing the plotted sections. Mappable contacts were adapted by comparing the frequency with which they occurred on the sections and the persistence with which they maintained their position with regard to other contacts.

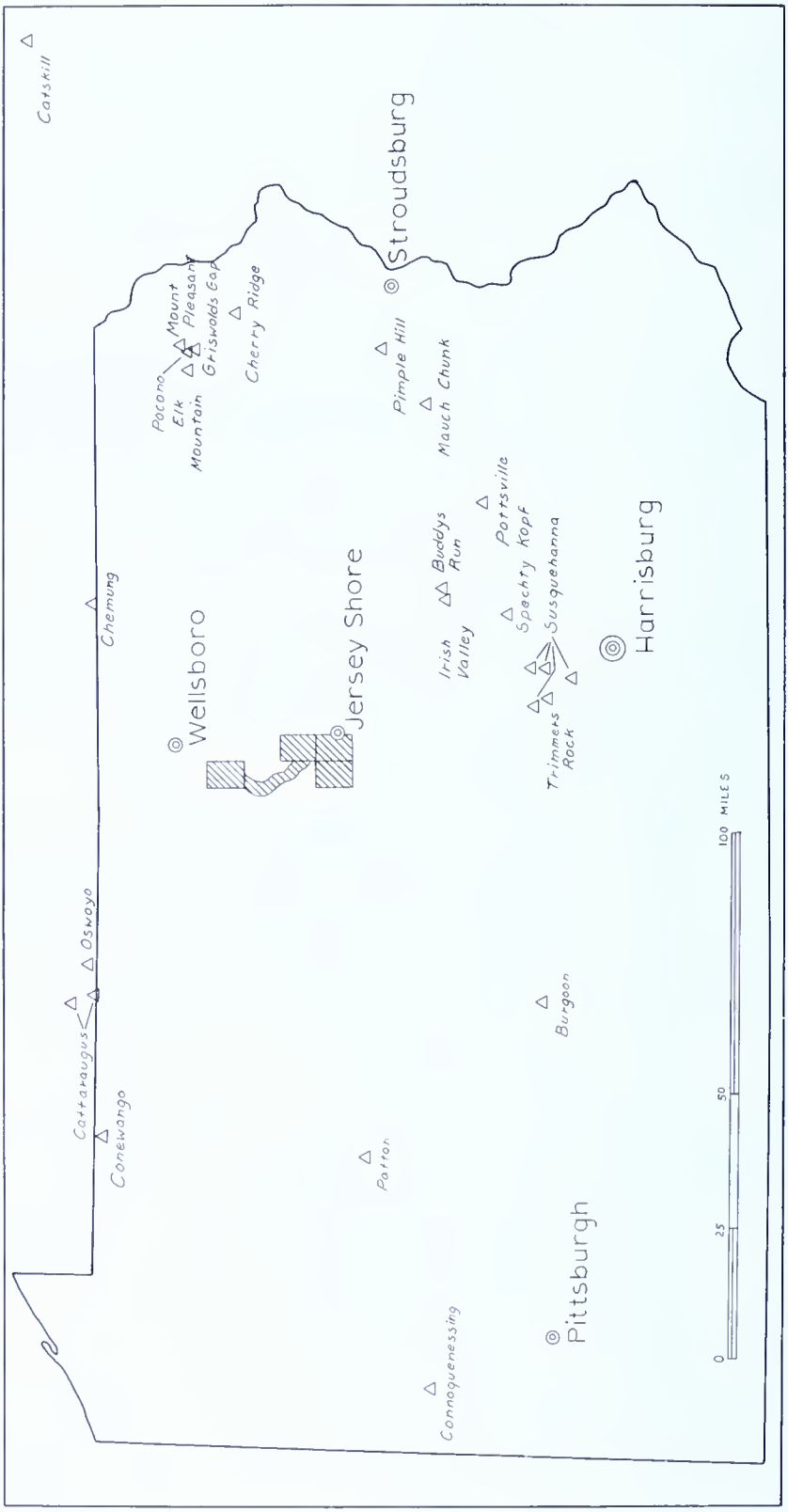

Figure 2. Sketch map showing location of type areas (triangles) of rock units that have been or might be recognized in or near the project area (cross-hatched).

The following rock sequence was recognized in the Cedar Run quadrangle:

Sandstone and conglomerate of Pennsylvanian age (basal 65 feet exposed):

Few exposures present. Float consists largely of light-gray to nearly white, fine- to very coarse-grained quartzose sandstone with some feldspar. Basal 6–15 feet is conglomeratic; pebbles are white and milky quartz up to 1¼ inches long. Basal contact may be disconformable.

Sandstone and conglomerate of Mississippian age (40–60 feet):

Composed largely of nearly white medium-grained quartzose sandstone. Basal 10 to 18 feet composed of coarse-grained to very coarse-grained sandstone with granules and pebbles of white and milky quartz rarely more than ½ inch long. A thin red mudrock unit is possibly present at top of sequence in one locality. Basal contact may be slightly disconformable.

Upper sandstone sequence (175–240 feet):

Largely light-tan and pale-olive, fine- to medium-grained, iron-stained, irregular-bedded quartzose sandstone. Several thin, nonresistant units of dark-greenish-gray and red shale and mudrock present in sequence, including one at or near top. Basal contact conformable.

Lower sandstone sequence (350–490 feet):

Predominantly light-olive-gray and light-tan, fine-grained argillaceous sandstone. Contains several nonresistant units of gray shale, red shale and mudrock, none of which could be traced across the quadrangle. Numerous lenses of sandy calcareous shale gall conglomerate and sandy crystalline limestone in lower part. A conglomerate, informally called the conglomerate at Cedar Run, is present in uppermost few inches to 6 feet. Most pebbles are milky quartz; some are pink and flesh-colored quartz; a few are chert, jasper, and fragments of older rocks.

Red-bed sequence (1407 feet exposed, basal 70 feet below drainage);

Heterogeneous sequence consisting of 50 per cent red rock and 50 per cent gray beds: 55 per cent sandstone and siltstone, and 45 per cent shale and mudrock. Units of gray sandstone are thicker and more closely spaced in upper part, whereas red shale, mudrock, and siltstone predominate in lower part. A cyclic repetition of rock types is evident, consisting of, from bottom to top: a thick channel-fill gray sandstone, brown sandstone, finer grained red sandstone and siltstone, silty and sandy red mudrock, a thick red shale and mudrock, and a thin green shale immediately below the next gray sandstone. Calcareous lenses similar to those in unit above are common in the bottom of gray sandstone units in the upper half of the sequence.

CORRELATION WITH SEQUENCE RECOGNIZED BY EBRIGHT

The writer previously (1963) compared the sequence in the Cedar Run quadrangle with the sequence described in 3 detailed stratigraphic sections by Ebright (1952, p. 26–32) to the south and southwest. These preliminary correlations have been largely substantiated by sections since measured by the writer southward along Pine Creek and southwestward toward Renova. The correspondence between the informal rock units in the Cedar Run quadrangle and the formal units recognized by Ebright is shown in Table 1.

The writer has recently restudied a series of exposures at Waterville (Fig. 1) described earlier by Ebright (1952, p. 31–32). When plotted

Table 1. *Comparison between strotigraphic sections of Ebright and Colton*

Ebright, 1952			Colton, 1963	
Pennsylvanian	Pottsville Group	Connoquenessing Sandstone (?) (conglomeratic at base)	Pennsylvanian	Sandstone and conglomerate of Pennsylvanian age (conglomeratic at base)
Mississippian		Mauch Chunk Series	?	(red float locally?)
	Pocono Group	Burgoon Sandstone (?) (conglomeratic at base)	Mississippian	Sandstone and conglomerate of Mississippian age (conglomeratic at base)
		Patton Red Shale (unnamed conglomerate)		(red mudrock locally) Upper sandstone sequence
Devonian		(Mount Pleasant (?) Red Shale) Oswayo Formation	?	(conglomerate at Cedar Run) Lower sandstone sequence (red beds near middle)
		Catskill Red Beds	Devonian	Red-bed sequence

graphically as columnar sections, my section and Ebright's compare remarkably well. However, the top of the Catskill as designated by Ebright is approximately 150 feet lower than the top of the red-bed sequence I recognized here and at other exposures near Waterville.

A KEY BED—THE CONGLOMERATE AT CEDAR RUN

The thin conglomerate at the top of the lower sandstone sequence was a very useful key bed in the Cedar Run quadrangle. It was found on all but one of the 52 traverses made across its stratigraphic position in the quadrangle. It crops out in few places, but float from this lithologically distinctive bed is common and easily recognized. The float material is widely distributed but vertically restricted, and the topographically highest occurrence of float apparently closely approximates the true position of the bed. Structural contours drawn on top of the conglomerate float in the Cedar Run quadrangle were quite smooth (Colton, 1963) with few irregularities. The interval between the conglomerate at Cedar Run and the next most easily recognized thin unit—the conglomeratic sandstone in the

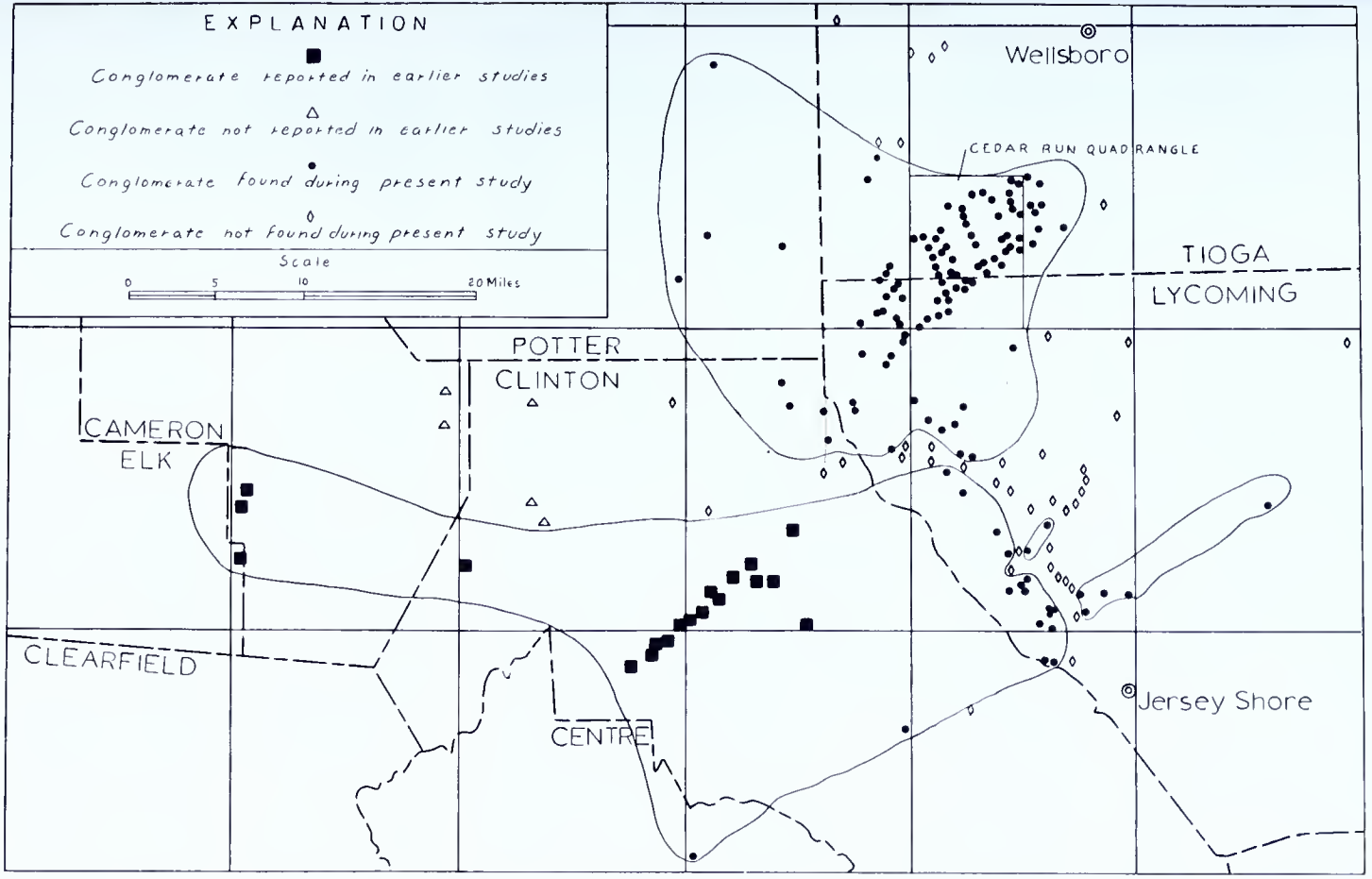

Figure 3. Map shawing approximate known extent (salid line) af conglomerate at Cedar Run. Includes localities described by Ebright and Ingham (1951), Ebright (1952), and Balger and Gause (1953).

base of the Mississippian sandstone and conglomerate sequence—is consistently about 200 feet in most sections.

A preliminary effort has been made to determine the extent of the conglomerate beyond the Cedar Run quadrangle (Fig. 3). It appears to correlate with the thin conglomerate reported by Ebright and Ingham (1951, p. 9, 29, 33), Ebright (1952, p. 8, 27–28, 31, and Pl. 2), and Bolger and Gouse (1953, p. 6, 29, 31) in the lower part of their Pocono Group at 19 localities in Elk, Cameron, Clinton, and Lycoming Counties. Including the localities described by the above workers, the conglomerate at Cedar Run has to date been found at 148 places in six counties lying within 23 7½-minute quadrangles. Although its maximum extent has not been accurately delineated in most directions, it appears to underlie an area of at least 800 square miles. It probably was originally deposited throughout an area of about 1,000 square miles, if the eroded portion along the crests of anticlines is included.

CORRELATIONS ALONG PINE CREEK

All mappable units in the Cedar Run quadrangle can be traced southward to the Allegheny Front—a distance of about 28 miles.

From north to south the red-bed sequence thickens from slightly more than 1400 feet to approximately 2000. In both areas its base is drawn at the top of the highest occurrence of marine fossils of the underlying thin-bedded predominantly marine sequence called the Chemung by Willard (1939, p. 328–329, and Fig. 93). Throughout the study area thick units of gray sandstone are present in the upper part of the red-bed sequence. To date it does not seem that any of the gray sandstone units can be mapped over large enough areas to be designated as formations or members.

The lower sandstone sequence thins slightly southward, apparently as gray sandstone in its lower part is replaced by red shale, mudrock, and siltstone at progressively higher stratigraphic positions. As a result the strata that correlate with Ebright's Oswayo formation thin from about 200 to 250 feet in the Cedar Run quadrangle to not more than 70 feet along the Allegheny Front.

One to three nonresistant units containing red shale, mudrock, and siltstone are present near the middle of the sequence in the Cedar Run quadrangle. They apparently represent discontinuous tongues or lentils and could not be mapped across the quadrangle. In the southern part of the study area a relatively thick red rock unit is present in the lower one-third of the sequence. It presumably is equivalent to one or more of the red units to the north, and probably is equivalent to the Mount Pleasant Red Shale of Ebright (1952, p. 8, Pl. 2).

The key conglomerate at the top of the lower sandstone sequence also changes southward. Whereas it is uniformly thin, relatively fine-grained, and seldom absent in the Cedar Run quadrangle, it is more variable in thickness, commonly coarser-grained, and present only locally to the south. The maximum pebble size increases from about one inch to about 2½ inches along this part of Pine Creek. At the northernmost locality examined outside of the project area, the largest pebbles are about ¼ inch in diameter. These data suggest that the conglomerate may have been spread uniformly as a sheet deposit to the north and accumulated as channel deposits to the south.

The upper sandstone sequence is more poorly exposed than the units below and is more difficult to study. It thickens from about 200 feet in the north to about 250 feet in the south, but otherwise changes very little. Correlations, incomplete as of this date, suggest that there may be a sparsely conglomeratic nearly white sandstone in the upper part of the sequence in the southern part of the area. The conglomeratic sandstone is very similar lithologically to the conglomeratic sandstone in the base of the overlying sequence.

A thin red rock unit near the top of the upper sandstone sequence is visible in many sections throughout the area and appears to correlate with the Patton Red Shale of Ebright (1952, p. 7, Pl. 2). The red unit apparently is covered by talus in some places but is absent in others.

The sandstone and conglomerate sequence of Mississippian age is difficult to study because its upper part is rarely exposed. From a total thickness of only 40 to 60 feet in the Cedar Run quadrangle, it thickens to at least 150 feet in the southern part of the area. However, Pennsylvanian rocks have not yet been observed in contact or even in close proximity to Mississippian rocks in the central and southern parts of the area.

The conglomeratic sandstone at the base of the sequence is present at most localities examined. However, incomplete field data show that pebbles are scarcer and less evenly distributed to the south than in the Cedar Run quadrangle.

A small area in the Cedar Run quadrangle is covered by red mudrock and shale float that may be stratigraphically equivalent to the Mauch Chunk Series of Ebright (1952, p. 7, Pl. 2). Similar red float at approximately the same stratigraphic position has been found in local but larger areas in the vicinity of Waterville.

Sandstone and conglomerate of Pennsylvanian age were mapped in the Cedar Run quadrangle and have been observed at a few widely separated localities in the southern part of the study area. However, study of these rocks is too preliminary to be described further at this time.

SOME POSSIBLE CORRELATIONS

A great number of correlations are possible between rock units comprising the upper Upper Devonian and Mississippian column in the study area and rocks of comparable age in other parts of Pennsylvania. I will discuss only a few of the possibilities in general terms and will champion none of them.

It is possible that the formal names recognized by Ebright, Fettke, and Ingham (1949), Ebright and Ingham (1951), Ebright (1952), and Bolger and Gouse (1953) in the area west and southwest of the project area can be appropriately applied in the study area. This presupposes, however, that the named rock units are coextensive and lithologically similar to rock units bearing the same name at their type localities in other parts of Pennsylvania. That this condition exists over such large areas for all of the rock units involved is highly unlikely. For example, the Oswayo as recognized in north-central Pennsylvania is not lithologically like the Oswayo at its type locality in New York (Glenn, 1903).

It is possible that new stratigraphic names would be justified considering the remoteness of the study area from other areas that have been mapped in detail. Certainly the key conglomerate might well be formally recognized as a member. There are, of course, valid objections to adding a number of new names to the literature.

It is also possible that some names recently proposed for rocks of approximately the same age in other parts of Pennsylvania can be appropriately applied in the study area. For example H. H. Arndt (oral communication, 1962) noted the similarity—in lithology and stratigraphic position—of some rocks in the study area with rocks recently named the Irish Valley, Buddys Run, and Spechty Kopf Members of the Catskill Formation in the western part of the Anthracite region (Arndt and others, 1962). If appropriate, these names would encompass the section extending from the upper part of Willard's Chemung to the base of the Burgoon (?) Sandstone of Ebright.

The last possibility to be discussed here—and probably the most logical—is that elements of the three solutions above should be combined. Some of the names used by members of the Pennsylvania Geological Survey to the west and southwest probably are appropriate in the present area; some new locally derived names probably will be necessary; and some recently proposed names from other parts of the State probably should be extended into the area.

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Petrography of the Catskill Facies in Three Localities from Central Pennsylvania[1]

ABSTRACT

Three stratigraphic sections in the Catskill facies, located near the central Pennsylvania communities of Lockport, New Buffalo and Red Rock, were studied in detail and samples were collected from them for petrographic analysis. The vertical distribution of the four major lithologies in the Catskill facies was determined in the Lockport and New Buffalo sections.

Three fundamental rock properties and two derived properties were estimated by measuring 15 variables on each of 72 samples, including 12 samples of red and 12 of gray rocks from each locality. The number of variables used to estimate the three fundamental rock properties included eight for mineral composition, four for grain size and one for grain shape. In addition, estimates were made of the derived properties, bulk density and effective porosity. Correlation matrices for red and gray rocks show the degree of binary linear dependence among the measured variables.

Comparisons made between the ranges of the variable means in the same rock type among the three areas showed statistically significant areal differences only between the means of micaceous rock fragments plus matrix and quartz proportions, bulk density and effective porosity in the gray rocks and mica and opaque proportions in the red rocks. In every case the areal differences in means exist between New Buffalo and the other two areas. All of the significant differences found in variable means among these three areas can be explained in terms of sorting effects resulting from minor local differences in geography, geomorphology and perhaps climate.

Much of the opaque matter in the red rocks is really an iron oxide stain or coating on other minerals, especially on micaceous rock fragments and matrix.

In all probability, the red and gray rocks in all three localities have a common source area and, except for local variations in sorting, the depositional environment for each rock type was very similar in all three areas.

INTRODUCTION

A thick series of red and gray or green Upper Devonian sandstone, siltstones and shales, commonly called the Catskill Formation, covers a large area of the eastern two-thirds of Pennsylvania. The stratigraphic relationships between these Pennsylvania sediments and the tremendous series of red beds in the Catskill Mountains of New York, from which they

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get their name by inferred correlation, are not yet fully understood. Part of the confusion arises from the lack of persistent fossil or marker horizons which can be used to correlate between areas within the dominantly red graywacke and shale sequence. Furthermore, it is now well recognized that in Pennsylvania this Catskill facies is time transgressive, with the bottom of the sequence lying on progressively younger, fossiliferous marine rocks toward the west. The red sequence finally pinches out altogether and the entire Upper Devonian is a normal marine sequence in the extreme western part of Pennsylvania.

The literature dealing with the Catskill facies is long and involved, including over 200 papers. The vast majority of these works are concerned with the stratigraphy, structure, paleontology and paleogeography of these rocks. Many of these publications, such as those by Barrell (1913, 1914a, 1914b), Chadwick (1936), and Willard (1939), are quite detailed, well known and provocative contributions. However, relatively few of these papers contain detailed descriptions of the mineralogy and petrography of the various lithologies present in the Catskill facies and those that do, such as the paper by Mencher (1939), are concerned with areas other than central Pennsylvania. Consequently, there is a definite lack of knowledge about the rock properties of the Catskill facies in this region and the primary objective of present research is to start filling in this gap.

Specifically, the objectives of this research are to: (1) determine the major rock types and their relative proportions in the Catskill facies in three localities in central Pennsylvania, (2) determine the significant variations in composition, texture and derived properties of the coarser grained Catskill rocks among the three areas and also between the red and non-red or gray rocks across the areas*, (3) determine the linear relationships (correlations) existing between these same properties within the red and gray lithologies and (4) summarize the geologic significance of the results obtained from the above determinations.

FIELD INVESTIGATION

Basis for Selecting Field Areas

After a preliminary investigation, three localities were selected for detailed study. They were chosen for the following reasons: (1) in each of them there are good exposures of fresh rock and these exposures are distributed through the entire vertical sequence, (2) they have few structural complications, (3) the top and bottom contacts are definable although not always exposed and (4) the positions of the three areas relative to the

*The present report only includes detailed comparisons between the same rock types among the three areas. Comparisons between red and gray rocks will be included in a future Ph. D. thesis now in preparation by the author.

inferred source area of the Catskill sediments is such that it may be possible to relate any differences found among the areas to the distance from the source rocks of the three areas. The exact locations of the localities are given in Table 1.

Table 1. *Locations of the Three Sections Investigated in This Study*

Locality	*Location*
1. Lockport	Lockhaven 15′ Quadrangle, Longitude 77° 28 to 29′ West, Latitude 41° 10 to 11′ North
2. New Buffalo	Harrisburg and Millersburg 15′ Quadrangles, Longitude 76° 59′ West, Latitude 40° 27 to 31′ North
3. Red Rock	Bloomsburg and Laporte 15′ Quadrangles, Longitude 76° 17 to 25′ West, Latitude 41° 14 to 19′ North

Figure 1 shows the locations of the three areas along with the position of the Early Chemung shoreline and river systems, based on Willard's (1939) data. The Red Rock and New Buffalo localities form a line which parallels this inferred shoreline and these two areas are also 50 miles closer than Lockport to the problematic southeastern Pennsylvania source area for the Catskill sediments in these regions.

Thickness of the Catskill Facies

The most outstanding feature of the Catskill facies is its large proportion of red-colored units. Unfortunately, however, in most areas the change

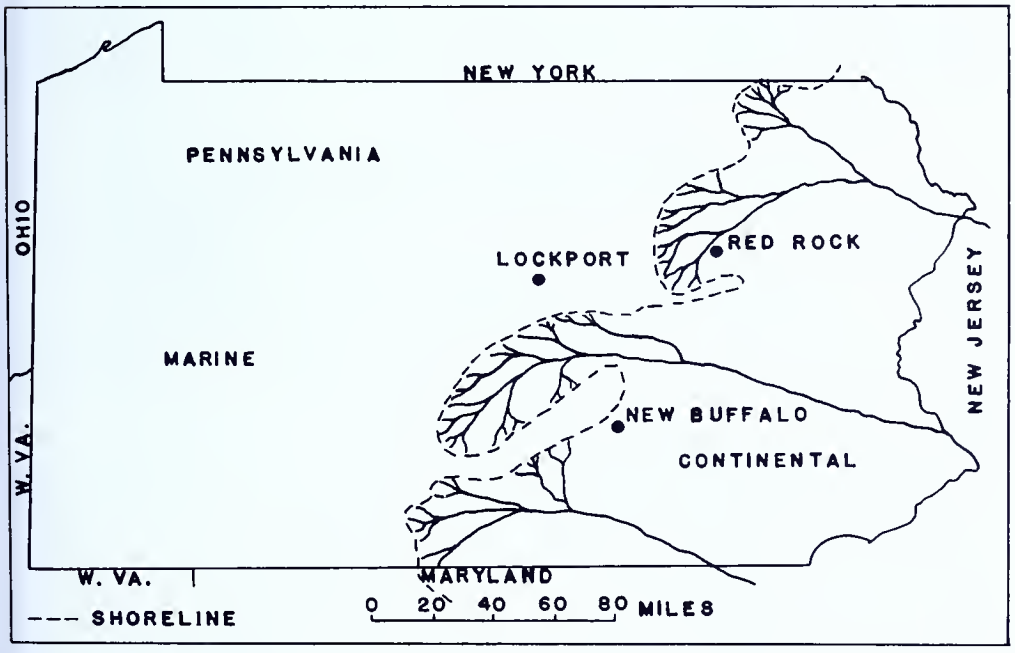

Figure 1. Map of the three areas investigated (circles) and their relationship to the inferred shoreline (dashed line) and river distributary systems of Early Chemung time as postulated by Willard (1939, figure 71).

from the underlying non-red, often fossiliferous, clastic beds to the typical, interbedded red, green and gray Catskill rocks is not very distinct or sharp. The change may be gradational, it may be interfingering or it may be a combination of these two. This complex relationship exhibited by the lower contact poses a serious problem for field mapping, thickness determinations and other stratigraphic considerations.

Fortunately, it is a less serious problem in a petrographic study such as this one. The present work is based on samples collected from entire sections, and the contact zone, which usually forms less than one per cent of any given section, presented a problem only in the New Buffalo area. In that area a 600-foot thick transition zone required the arbitrary selection of a basal contact. The thickness given in Table 2 for this locality includes this zone.

Table 2. *Measured Thicknesses of the Catskill Facies in Three Localities in Central Pennsylvania*

Locality	*Thickness*
1. Lockport	1,940 feet
2. New Buffalo	5,400 feet
3. Red Rock	5,760 feet

The thickness of the Catskill facies ranges from zero to about 10,000 feet, reaching a maximum in the Catskill Mountains of New York. In Pennsylvania, it is reported to be 7,500 feet thick in the Lehigh Valley area (Willard, 1939) and thins to the west and northwest until it disappears altogether in the western part of the state. Table 2 gives the thicknesses measured at each of the localities in this study.

Basic Lithologic Groups and Their Distribution

Although many interesting lithologies are encountered, only four basic types make up over 99 per cent of the stratigraphic sections studied. These are (1) red fine siltstone and shale, (2) red sandstone and coarse siltstone, (3) gray and green sandstones and coarse siltstones and (4) gray and green fine siltstones and shales. The first group is by far the most abundant, followed by the other three groups which are about equal in amount.

Table 3 summarizes the distribution of these four lithologies in the Lockport and New Buffalo areas. The data in this table were determined by essentially "point counting" the exposed portions of the sections in these two areas. The counting was accomplished by selecting a point at the base of the exposure, recording its lithologic type, then recording the lithology of the point one foot above and so on up the section. Covered intervals were skipped and the process repeated in all the exposed units. A geologic hammer served very nicely as a "ruler".

Table 3. *Statistical Summary of Field Data**

Area		1 *No. of Points*	2 *Ss.*	3 *Silts. & Sh.*	4 *Red Units*	5 *Gray Units*	6 *Red Ss.*	7 *Red Sh. & Silts.*	8 *Gray Ss.*	9 *Gray Sh. & Silts.*	10 *Other Units*
Lockport "Point Count"	Top	327	60.5	38.2	42.5	56.2	11.3	31.2	49.2	7.0	1.3
		326	35.2	64.2	74.9	24.5	14.4	60.5	20.8	3.7	0.6
		326	32.8	66.6	97.6	1.8	31.3	66.3	1.5	0.3	0.6
	Base	326	31.9	68.1	97.5	2.5	29.4	68.1	2.5	0.0	0.0
	Total	1305	40.1	59.3	78.1	21.3	21.6	56.5	18.5	2.8	0.6
New Buffalo "Point Count"	Top	547	49.5	49.0	57.1	41.4	14.8	42.3	34.7	6.7	1.5
		500	14.6	85.0	82.6	17.0	6.8	75.8	7.8	9.2	0.4
		500	8.2	91.8	68.6	31.4	3.6	65.0	4.6	26.8	0.0
	Base	500	10.0	89.8	54.8	45.0	4.6	50.2	5.4	39.6	0.2
	Total	2047	21.2	78.2	65.5	33.9	7.5	57.9	13.6	20.3	0.5

*All figures in columns 2–10 are in per cent. Each point (column 1) is equivalent to about 1 foot of exposed stratigraphic section so the total number of points is approximately equal to the total amount of exposed stratigraphic section in each area.

In Table 3 the exposed Lockport section is divided into four equal parts and the percentages are recorded for each of these parts and for the total. It is important to note here that these "fourths" do not divide the whole Catskill facies into equal fourths because most of the 600 plus feet of covered interval in this section are in the basal third. The covered intervals probably are dominated by the softest rock type and, since the softest rock is the red fine siltstones and shale group, this group is probably even more dominant than shown by the percentages in Table 3.

In the case of the New Buffalo section the lower three subdivisions represent almost continuous exposures starting at the arbitrarily chosen basal contact and continuing up through about the first 1,800 feet. The upper subdivision includes the uppermost exposed 550 feet of section up to the contact with the Pocono Formation. Unfortunately, the whole middle of the section is missing but probably is formed primarily of the red fine siltstone and shale group.

Aside from the exceptional dominance of the red fine siltstone and shale group, the major distribution feature to note in Table 3 is the marked increase in the proportion of gray sandstone in the top part of both sections. Although the exposed Red Rock section was not measured because it has relatively few fresh rock exposures and because its low dip puts a good deal of what exposure there is on inaccessible cliffs, it shows essentially the same relationships as the other areas. In particular, again there is a marked increase in the proportion of gray sandstone and coarse siltstone near the top of the section.

Sampling Procedure

During measurement of the sections, samples were collected at approximately every 50 feet of the exposed portions. These samples were taken back to the laboratory where they were examined under the binocular microscope, classified into the four lithologic types, and rated according to their degree of weathering. After eliminating all of the weathered specimens, 36 red and 36 gray samples were selected for detailed petrographic analysis from the sandstone and coarse siltstone rock group. Each of the two sample groups contains 12 samples from each of the three areas and in each of these groups of 12 samples six samples were randomly chosen from available specimens of the lower half and six from the top half of their respective stratigraphic sections.

VARIABLES AND THEIR MEASUREMENT

According to Griffiths (1961), a rock has five fundamental properties upon which all its other properties depend; these properties are mineral composition, grain size, grain shape, grain orientation, and grain packing. He notes that all other properties may be regarded as derived because in

order to measure and understand them it is first necessary to have some knowledge of these fundamental properties.

The 15 variables listed in Table 4 were measured for each of the 72 samples. Three of the five fundamental properties, mineral composition, grain size, and grain shape, were estimated by variables 1–8, 9–12, and 13 respectively and, in addition, two derived properties, bulk density and porosity (variables 14 and 15), were measured.

Table 4. *Variables Measured*

Variable Number	*Variable Number*	*Variable Number*
1. Quartz	6. Feldspar	11. σa-phi (sorting of a axis)
2. Fine Quartz	7. Carbonate	12. σb-phi (sorting of b axis)
3. Undulose Quartz	8. Opaques	13. b/a (estimate of grain shape)
4. Micaceous Rock Fragments + Matrix	9. a-phi (long axis)	14. Bulk Density
5. Mica Grains	10. b-phi (short axis)	15. Effective Porosity

Composition

The eight compositional variables were all measured by point counting (Chayes, 1956 and Griffiths, 1960) 700 points on one thin section for each of the 72 samples. A preliminary study showed that the eight mineral classes listed in Table 4 and defined below could be tabulated rapidly and, in most cases, accurately. Actually, at first it was hoped that silica cement could also be determined but it was found that no suitable criteria are available for uniquely classifying it. In too many cases it cannot be distinguished from the quartz grain upon which it has grown.

On the other hand, finely crystalline quartz is commonly present along grain edges, in pore spaces and in clusters scattered through the rock. This quartz, which is probably a product of diagenesis (recrystallization), was counted as a separate class in lieu of silica cement. In the finer grained rocks some difficulty was encountered in distinguishing it from normal quartz and, indeed, this may account for the fact that finely crystalline quartz has a high positive correlation coefficient with normal quartz in these rocks (See Table 5). Because of this fact, the usefulness of the class has been reduced somewhat and it can be argued with some validity that the fine quartz and quartz classes should be combined.

The same argument applies to the undulose quartz class but, on the other hand, the fact that both the finely crystalline and undulose quartz

Table 5. *Linear Correlation Caefficient Matrix for the 15 Variables Determined on the 36 Red Samples*

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1 Quartz	1.00	.59*	.78*	−.77*	.14	.34	−.24	−.76*	−.70*	−.73*	−.52*	−.52*	.26	−.81*	.64*
2 Fine Quartz	—	1.00	.56*	−.37	.03	.06	−.44*	−.66*	−.40	−.40	−.44*	−.15	.05	−.48*	.29
3 Undulose Qtz	—	—	1.00	−.47*	−.06	.25	−.26	−.79*	−.76*	−.76*	−.54*	−.54*	.05	−.76*	.56*
4 MRF + Matrix	—	—	—	1.00	−.19	−.19	.01	.27	.47*	.49*	.35	.31	−.21	.56*	−.57*
5 Mica	—	—	—	—	1.00	−.08	.28	−.24	−.05	−.07	−.10	−.01	.21	−.08	.23
6 Feldspar	—	—	—	—	—	1.00	−.12	−.25	−.35	−.36	−.01	−.17	.07	−.16	.13
7 Carbonate	—	—	—	—	—	—	1.00	.09	.13	.14	.10	.03	−.08	.30	−.06
8 Opaques	—	—	—	—	—	—	—	1.00	.65*	.66*	.52*	.47*	−.13	.66*	−.46*
9 a-phi	—	—	—	—	—	—	—	—	1.00	.99*	.50*	.64*	.08	.67*	−.59*
10 b-phi	—	—	—	—	—	—	—	—	—	1.00	.52*	.66*	−.02	.68*	−.59*
11 σ a-phi	—	—	—	—	—	—	—	—	—	—	1.00	.81*	−.14	.38	−.21
12 σ b-phi	—	—	—	—	—	—	—	—	—	—	—	1.00	−.19	.46*	−.30
13 b/a	—	—	—	—	—	—	—	—	—	—	—	—	1.00	−.10	.01
14 Bulk Density	—	—	—	—	—	—	—	—	—	—	—	—	—	1.00	−.87*
15 Effective Porosity	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1.00

*1% significance level is at r = 0.42 for n = 36

classes are not correlated with quartz in the gray rocks (Table 6) is some justification for separating them, at least in the case of the gray rocks.

Definition of Composition Classes

Quartz—all colorless, untwinned, low relief grains with low first order birefringence and not possessing undulose extinction or not being finer than 0.05 mm. in maximum diameter.

Fine Quartz—all recognizable quartz finer grained than 0.05 mm. in maximum diameter.

Undulose Quartz—all quartz coarser than 0.05 mm. in maximum diameter and which possesses a wavy extinction pattern in polarized light. In order for a quartz grain to be included in this class, the microscope stage must be rotated through an arc of at least 10°, beginning with the first sign of extinction, before the birefringence of the whole grain is extinguished.

Feldspar—all twinned grains which otherwise have properties similar to those of quartz.

Mica—grains larger than 0.05 mm. in maximum diameter which have the optical properties of either muscovite or biotite (but not chlorite). Nearly all of the mica in these rocks is muscovite.

MRF + Matrix (where MRF stands for Micaceous Rock Fragments)—This class includes all rock fragments containing micaceous minerals (including chlorite) as well as all mineral grains finer than 0.01 mm. and all mica grains finer than 0.05 mm. in maximum diameter. All chlorite grains are included in this class.

Carbonate—all colorless grains with very high birefringence and relief. These grains nearly always show two good cleavages and are twinned. Rhombohedral shape is observed in some cases.

Opaques—all minerals opaque or semi-transluscent to transmitted light. In the case of the red-colored rocks the opaque matter is nearly 100 per cent 'orange-red reflecting' iron oxide cement or stain; in the gray rocks it is nearly 100 per cent 'dull-black reflecting' carbonaceous material. The gray rocks contain no, or only a trace of, iron oxide.

Others—all minerals not assignable to one of the above classes. This class, which includes all heavy or accessory minerals, is never present in amounts greater than one per cent.

All of the distinctions in grain size mentioned in the definitions of classes given above were estimated by the observer during the point count.

Texture

The five textural variables listed in Table 4 (numbers 9–13) were determined from the same thin sections on which the compositional measurements were made. In each thin section all five of these variables

Table 6. *Linear Correlation Coefficient Matrix for the 15 Variables Determined on the 36 Gray Samples*

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1 Quartz	1.00	.07	−.03	−.69*	.03	.01	−.02	−.20	−.53*	−.51*	.01	.17	−.01	−.66*	.72*
2 Fine Quartz	—	1.00	.25	−.51*	.10	.01	−.06	−.26	−.23	−.22	.39	.35	−.08	−.29	.23
3 Undulose Qtz	—	—	1.00	−.35	−.38	.17	−.23	−.27	−.49*	−.49*	.31	.43*	.24	−.18	.06
4 MRF + Matrix	—	—	—	1.00	−.10	−.04	−.27	.10	.65*	.62*	−.08	−.27	.05	.46*	−.52*
5 Mica	—	—	—	—	1.00	.02	−.04	.00	.42*	.45*	−.36	−.39	−.42*	.12	.00
6 Feldspar	—	—	—	—	—	1.00	−.20	−.08	.01	.01	−.20	−.15	−.02	−.05	−.03
7 Carbonate	—	—	—	—	—	—	1.00	.13	−.17	−.16	−.05	−.06	−.09	.27	−.18
8 Opaques	—	—	—	—	—	—	—	1.00	.17	.16	−.48*	−.33	.07	.37	−.24
9 a-phi	—	—	—	—	—	—	—	—	1.00	1.00	−.34	−.49*	−.32	.43*	−.42*
10 b-phi	—	—	—	—	—	—	—	—	—	1.00	−.34	−.49*	−.40	.42*	−.39
11 σ a-phi	—	—	—	—	—	—	—	—	—	—	1.00	.82*	.15	−.35	.24
12 σ b-phi	—	—	—	—	—	—	—	—	—	—	—	1.00	.24	−.36	.30
13 b/a	—	—	—	—	—	—	—	—	—	—	—	—	1.00	.01	−.12
14 Bulk Density	—	—	—	—	—	—	—	—	—	—	—	—	—	1.00	−.91*
15 Effective Porosity	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1.00

*1% significance level is at r = 0.42 for n = 36

were measured on 40 randomly chosen grains from the quartz composition class.

The quantity b-phi, or short grain size axis, is a log (phi) transformation of the length of the line perpendicular to two parallel tangents to the quartz grain when the tangents are positioned such that they have their minimum possible separation. The long grain size axis, or a-phi, is a log (phi) transformation of the length of the longest axis perpendicular to b-phi which is contained in the quartz grain. A detailed discussion of this measurement technique for grain size is given by Griffiths and Rosenfeld (1953).

The log transformation of the a and b axes measurements to phi units is the standard one first used by Krumbein (1938). The lengths of a and b, expressed in millimeters, are converted to: $-\log_2$ (millimeter value of a) = a-phi, and a similar expression for b-phi.

The sorting values for the a and b axes or sigma-a-phi and sigma-b-phi are sample estimations of the standard deviations calculated from the 40 grain measurements of the a and b axes after the latter have been converted to phi units.

$$\sigma \text{ a-phi} = 1/40 \sum_{i=1}^{40} (\text{a-phi}_i - \bar{x}_{\text{a-phi}})^2$$

$$\sigma \text{ b-phi} = 1/40 \sum_{i=1}^{40} (\text{b-phi}_i - \bar{x}_{\text{b-phi}})^2$$

As their name implies, these quantities are a measure of the sorting or the spread in size of axes of the quartz grains in each of the thin sections.

b/a is an index related to the shape of the quartz grains in their two dimensional sections as seen under the microscope. Here b and a are the millimeter values of the b-axis and a-axis, respectively, and because, by definition, b is always smaller than or equal to a, their ratio must vary between 0 and 1. In general, the higher the ratio, the more equant are the grains and the lower the ratio, the more elongate or needle-like they become.

Derived Properties

Bulk density and effective porosity were measured on rock chips immediately adjacent to the chips used in making thin sections. The effective porosity was determined by a vacuum saturation technique using kerosene as the fluid. For a review of the problem of porosity measurements see the papers by Griffiths (1949) and Rosenfeld (1950).

Bulk density measurements were made by weighing the samples first in air, then submerged in mercury, noting the temperature of the mercury

(t°C), and then calculating the bulk density from the formula:

$$\text{Bulk Density} = \frac{(\text{Specific gravity of Hg at t°C})(\text{Weight of sample in air})}{(\text{Weight of sample in air}) + (\text{Weight of sample in Hg})}$$

The bulk density and effective porosity determinations were made on the same rock chip.

LINEAR CORRELATIONS BETWEEN VARIABLES

In any attempt to interpret the geologic significance of variations between means for a number of variables it is desirable to check first on the relationships which may exist between the variables themselves. Linear correlation is an excellent statistical tool for accomplishing this purpose.

The quantity, r, where $r = \sum_{i=1}^{n} \frac{(x_i - \bar{x})(y_i - \bar{y})}{nSx\,Sy}$ is called the coefficient of linear correlation or, more commonly, the correlation coefficient between the sample values of the two variables x and y. In this expression $\bar{x}$ is the sample mean of the variable x, $\bar{y}$ is the sample mean of the variable y, Sx and Sy are the standard deviations of x and y, and n is the number of pairs of measurements (or sample values). The value of r ranges between 0 and 1, with a perfect linear relationship having the higher value and with no linear dependence having a zero value. It is important to note, however, that a zero value for the correlation coefficient does *not* imply that there is complete independence between the two variables concerned. They may be completely dependent in a non-linear fashion and an example of one such case is given on page 120 in Hoel (1954).

Tables 5 and 6 give the correlation coefficient matrices for the red and gray colored rocks respectively. Some of the high correlations between the variables in these two tables may be analyzed in terms of known relationships existing between them or in the light of what we might expect from previous experience, including geologic considerations. A word of caution should be included at this point. A high correlation coefficient between two variables does not necessarily imply any "cause and effect" relationship. If x and y are highly correlated neither of the statements "x causes y" and "y causes x" is necessarily true as both of them may be controlled by another factor or factors.

In both the red and gray rocks a-phi and b-phi have a near perfect linear relationship. This observation implies that quartz shape (axial ratio) remains constant over the entire range of the quartz grain size. A high correlation between the a and b axes is also expected on the basis of past experience with this measurement technique (Griffiths, 1958, and Pachman, 1961).

A high negative correlation between quartz and MRF + matrix is also

present in both red and gray rocks. Because these composition variables are not independent and because they are both always present in high concentrations, there is a possibly large induced negative correlation between them (Chayes, 1960). In fact, all the compositional variables are interdependent because their sum must total 100 per cent. Consequently, the significance values used in Tables 5 and 6, which are calculated under the assumption of complete independence between the variables concerned, are not strictly applicable to the correlations between any of the compositional variables. These correlations should be corrected by some undetermined factor in order to account for the induced or spurious negative correlations. This correction will be small for those variables like feldspar which are present in low amounts, and high for those variables like MRF + matrix and quartz which are present in large amounts. As a consequence of this dependence, an unknown but probably significant portion of the negative correlation between quartz and MRF + matrix is induced and, therefore, it is uncertain whether the correlation between these two variables would be significant if the effect of the spurious correlation were removed.

VARIATION OF VARIABLE MEANS AMONG AREAS

Table 7 summarizes the results of the mean measurements and subsequent statistical tests of their areal significance for the red sandstones and coarse siltstones. Table 8 gives the same data for the gray sandstones and coarse siltstones.

It is of interest to determine whether or not the means found for each variable differ significantly among the three areas. In order to do this it is necessary to find a suitable test for comparing three means at the same time. One such test is the Studentized Range test which is described by Bennett and Franklin (1954, p. 185). In applying this test it is assumed that all the samples are from populations with equal variance σ^2, and that all of the means come from samples of equal size. Column 6 in Tables 7 and 8 gives the results of this test as applied to the range of the means given in columns 2, 3, and 4. The null hypothesis underlying the test is: $\mu_{\text{Lockport}} = \mu_{\text{New Buffalo}} = \mu_{\text{Red Rock}} = \mu$. In Tables 7 and 8 (Column 6), S signifies that the range of the means is significantly greater than would be expected if the means were all equal and, therefore, the hypothesis of their equality must be rejected.*

While the second of the above assumptions is true in our case (N for each variable mean is 12) we have no *a priori* basis to support the first assumption. But this assumption can be checked by applying a statistical test known as "Bartlett's Test" (Bennett and Franklin, 1954, p. 196)

*All significance values mentioned in the present report are taken at the one per cent confidence level.

Table 7. *Results of Area Analysis for Red Colored Rocks*

Variable	1 Units for Columns 2, 3 & 4	2 Mean of Lockport Area	3 Mean of New Buffalo Area	4 Mean of Red Rock Area	5 Bartlett's Variance Test*	6 Student's "t" Test for Range*	7 Mean Test with Heterogeneous Variances*
Quartz	per cent	26.9	18.2	26.7	NS	NS	—
Fine Quartz	per cent	12.6	11.8	15.1	NS	NS	—
Undulose Quartz	per cent	6.8	3.9	5.0	NS	NS	—
MRF + Matrix	per cent	27.6	33.8	25.9	NS	NS	—
Mica	per cent	3.2	0.2	3.6	S	—	S
Feldspar	per cent	0.5	0.4	0.3	NS	NS	—
Carbonate	per cent	2.9	0.1	0.4	S	—	NS
Opaques	per cent	19.4	30.5	22.9	NS	S	—
a-phi	phi units	3.59	4.04	3.77	NS	NS	—
b-phi	phi units	4.30	4.75	4.48	NS	NS	—
σ a-phi	phi units	0.66	0.74	0.62	NS	NS	—
σ b-phi	phi units	0.65	0.72	0.66	NS	NS	—
b/a	no units	0.641	0.639	0.641	NS	NS	—
Bulk Density	gm/cc	2.66	2.70	2.64	NS	NS	—
Effective Porosity	per cent	2.4	1.0	2.7	NS	NS	—

*NS = Not Significant at the 1% confidence level and S = Significant at the 1% confidence level.

Table 8. *Results of Area Analysis for Gray Colored Rocks*

Variable	1 Units for Columns 2, 3 & 4	2 Mean of Lockport Area	3 Mean of New Buffalo Area	4 Mean of Red Rock Area	5 Bartlett's Variance Test*	6 Student's "t" Test for Range*	7 Mean Test with Heterogeneous Variances*
Quartz	per cent	31.8	22.4	30.7	NS	S	—
Fine Quartz	per cent	16.7	14.1	16.7	NS	NS	—
Undulose Quartz	per cent	10.1	13.2	10.0	NS	NS	—
MRF + Matrix	per cent	31.9	42.7	34.4	NS	S	—
Mica	per cent	3.3	2.8	4.0	NS	NS	—
Feldspar	per cent	0.4	0.5	0.2	NS	NS	—
Carbonate	per cent	2.9	0.2	0.5	S	—	NS
Opaques	per cent	2.8	3.9	3.4	NS	NS	—
a-phi	phi units	2.68	3.03	2.68	NS	NS	—
b-phi	phi units	3.34	3.68	3.33	NS	NS	—
σ a-phi	phi units	0.70	0.67	0.71	NS	NS	—
σ b-phi	phi units	0.69	0.66	0.73	NS	NS	—
b/a	no units	0.651	0.660	0.659	NS	NS	—
Bulk Density	gm/cc	2.63	2.67	2.62	NS	S	—
Effective Porosity	per cent	2.5	0.9	2.8	S	—	S

*NS = Not Significant at the 1% confidence level and S = Significant at the 1% confidence level.

for homogeneity of several variances. This test has been applied to the variances for each of the variables in Tables 7 and 8 and the results are given in column 5 of these same tables. The null hypothesis tested is: $\sigma^2_{\text{Lockport}} = \sigma^2_{\text{New Buffalo}} = \sigma^2_{\text{Red Rock}} = \sigma^2$. In Tables 7 and 8 this hypothesis is rejected in only four cases, those of mica and carbonate variances in the red rocks and carbonate and effective porosity variances in the gray rocks. For all of the remaining variables the results from the Studentized Range test have been accepted as valid.

Finally, a statistical test, described by Snedecor (1956, p. 287), tests the hypothesis that the means are the same even in the presence of heterogeneous variances. This test, which Snedecor (1956) notes is not exact, was applied to those variables in Tables 7 and 8 which gave significant results to Bartlett's Test. The null hypothesis is the same as that for the Studentized Range test, namely: $\mu_{\text{Lockport}} = \mu_{\text{New Buffalo}} = \mu_{\text{Red Rock}} = \mu$. Significant and not significant (S and NS) have the same meanings as they do in the Studentized Range test described above.

There is significant areal difference only between the means of mica and opaques content in the red colored rocks and between the means of quartz, MRF + matrix, bulk density and effective porosity in the gray rocks. Quartz, MRF + matrix, bulk density, and effective porosity are borderline cases in the red rock group and feldspar and σ a-phi are significant at the five per cent confidence level in the gray set.

An inspection of the significant mean values listed in columns 2, 3 and 4 in Tables 7 and 8 shows that in every case it is the New Buffalo area which differs markedly from the other two localities. Its red rocks contain less mica and more opaque matter and its gray rocks contain less quartz and more MRF + matrix, have a higher bulk density and a lower effective porosity than do the corresponding rock types in the other two areas. This trend even carries through to those means which are not significantly different in a statistical sense.

This observation is surprising in view of the nearly identical thicknesses (Table 2) and postulated distances from the source area (Figure 1) of the New Buffalo and Red Rock localities. Nevertheless, the significant differences in petrographic properties between these areas must reflect differences in their geologic history. They may be explained by assuming (1) differences in source rocks, (2) differences in sorting during transportation and deposition, (3) differences in depositional environment, (4) differences in post-depositional history, including diagenetic changes, or (5) some combination of (1) through (4).

Although there are these petrographic differences between areas, the frequent interbedding of the two rock types in all three areas, the nearly identical lithologies and lithology distributions (Table 3) in all three areas and the remarkably similar mineralogy of all the rock types and

areas are strong evidence for a common source area for their clastic components. Furthermore, this same evidence indicates that the depositional environment of each rock type was essentially the same in all three areas. However, even if they had the same source area, the depositional environments of the red and gray rocks were quite different.*

Assuming the Catskill sediments in all three localities have a common source area, how can the observed differences in stratigraphic thicknesses of these areas be reconciled with their observed petrographic differences?

In order to answer this question it is necessary to again examine the correlations in Tables 5 and 6. First note that bulk density and effective porosity have a high negative correlation in both red and gray rocks. This result is expected because, by definition, effective porosity is inversely proportional to bulk density. Consequently, since they vary alike, if the range of the means is significant for one of them it also should be for the other. The same argument applies to the observation that the range in means is significant for both the quartz and MRF + matrix contents of the gray rocks. An explanation for the high negative correlation between quartz and MRF + matrix contents was given earlier in this report (See the section on Linear Correlations Between Variables).

The low effective porosity of the gray New Buffalo rocks relative to those of the other areas probably is a reflection of the fact that these same rocks have a higher MRF + matrix content. Any micaceous rock fragments and matrix present in a rock are normally found in pore spaces and in the channels between grains. These materials tend to clog channels and pore spaces, thereby reducing the effective porosity of the rock. The further observation that there is a significant negative correlation between MRF + matrix and effective porosity for both the red and gray rocks also supports this conclusion.

Although all three localities probably have the same source area, the fact that the New Buffalo gray rocks contain more MRF plus matrix suggests that during their water transportation and deposition the 'gray' sediments travelling to the New Buffalo area were better sorted, on the average, than those deposited in the other areas. During this sorting the quartz would tend to be winnowed out, thereby increasing the proportion of MRF + matrix in the sediment. At the same time the average grain size of the quartz would be reduced as the larger grains would be removed first. Although this conclusion appears to be incongruous with the positions of the three localities relative to their inferred source area, the distance from source area is not the only factor which affects sorting in a sediment. Many other factors, such as distance from a main sediment

*The author intends to present the evidence for this conclusion in a Ph.D. dissertation currently in preparation in the Dept. of Mineralogy, Penn. State Univ.

distributary, local gradients, and local climate may have a pronounced effect on the sorting of sediments in a small, local region. All the significant differences found in variable means among these three areas can be explained in terms of sorting effects resulting from local differences in geography, geomorphology and perhaps climate.

The cause for the difference in opaque content of the red rocks between New Buffalo and the other localities is not readily apparent. Before seeking an explanation for this difference it is necessary to examine the nature of the opaque matter itself.

Chemical analyses run on six red samples, including two from each locality, show little difference among them in either total iron or ferric iron content. The highest total iron content measured in any sample was 4.5 per cent Fe. Consequently, the 30.5 per cent of opaque matter in the red New Buffalo rocks hardly can be a pure iron oxide such as hematite. Much of it really must be an iron-oxide coating or stain on other minerals. The compositional class that would be most affected by such staining is the MRF + matrix group. Therefore, it is probable that most of the material classified as opaque matter during point counting of the red rocks really belongs in the MRF + matrix class. These conclusions are further supported by comparing the bulk density and total iron contents of the red and gray rocks. No significant difference in either bulk density or total iron content (based on analyses of six red and six gray samples) was found between the red and gray rocks, although the red beds have a much higher proportion of ferric iron over ferrous iron than the gray rocks.

Returning to the problem of an excess amount of opaque matter in the New Buffalo rocks relative to that in rocks from the other two localities, Table 5 shows a high negative correlation of opaque content with quartz grain size. This correlation indicates that a proportionately greater 'masking' of the matrix by iron-oxide staining may occur in the finer grained than in the coarser grained red rocks. This conclusion concurs with the impression one gets when point counting the fine-grained red rocks. In these rocks it is often difficult to classify a grain as opaque or non-opaque because all gradations between the two are present.

The New Buffalo area has the finest grained rocks of any area. Consequently, the significantly higher content of opaque matter in these same rocks very likely results from a proportionately greater 'masking' of the matrix minerals by iron-oxide staining. The nearly identical ferric-iron content in the red rocks of all three areas also implies that the high content of opaque matter in the New Buffalo rocks is not caused by a higher concentration of ferric iron oxide but probably is caused by this 'masking' effect.

If these conclusions are correct, then most of the opaque class in the red rocks really is iron-oxide-stained MRF + matrix and we are justified

in adding the two together to form a better estimate of the abundance of MRF + matrix. If this is done for the red rocks in all three areas, the result is that the mean of this combined group is significantly higher for the New Buffalo rocks than for those in the other two areas. This result is an expected consequence of the previously stated conclusion that the New Buffalo sediments, as a group, are better sorted than those of the other areas.

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Lithology, Subdivision and Correlation of the Catskill Formation in East-Central Pennsylvania.

ABSTRACT

The Catskill Formation in the western Anthracite and middle Susquehanna-lower Juniata Valley regions is composed of a thick (5000 to 9400 feet) largely non-marine sequence of red, gray and olive shales, siltstones, sandstones and conglomerates ranging in age from Late Devonian to Early Mississippian. Portions of the formation are dominated by one or more distinct lithologies which provide readily mappable member units that are traceable through two or more 15-minute quadrangles.

The topmost member is the Spechty Kopf which is present nearly everywhere in the area mapped. The Spechty Kopf is olive and gray sandstone and conglomerate with some interbeds of olive, gray and grayish-red siltstones. The member is unconformably overlain by the Pocono Formation. Locally in the southern part of the western Anthracite region the unconformity cuts down through the Spechty Kopf Member into an older member.

The Buddys Run Member underlies the Spechty Kopf in east-central Pennsylvania northwest of an arbitrary nomenclatural division line. The Buddys Run is dominantly grayish-red shale, siltstone and sandstone with some gray, tan and buff shale and sandstone.

Southeast of the nomenclatural division line the rocks correlative with the Buddys Run Member are separated into other members. Underlying the Spechty Kopf is the Cherry Ridge Member which is dominantly red sandstone, siltstone and shale. In the Duncannon region rocks equivalent to the Cherry Ridge are subdivided into two unnamed members: an upper sandstone member and an upper redbed member. The first of these is gray sandstone with some conglomerate and some red interbeds; the second is mainly red shale, siltstone and sandstone.

Underlying the Cherry Ridge Member is the Honesdale Sandstone Member. This member is called the Clark's Ferry Member by the Pennsylvania Geological Survey in the vicinity of Duncannon and consists of gray to red, resistant conglomerate, sandstone and shale.

Below the Honesdale Member is the Damascus Member, a unit largely composed of red shale, siltstone and sandstone. Near Duncannon this unit is called the lower redbed member.

The lowest unit of the Catskill Formation is the Irish Valley Member. This member is present throughout the area mapped and is characterized by many alternations of red and gray shale, siltstone and sandstone, some of which contain marine fossils.

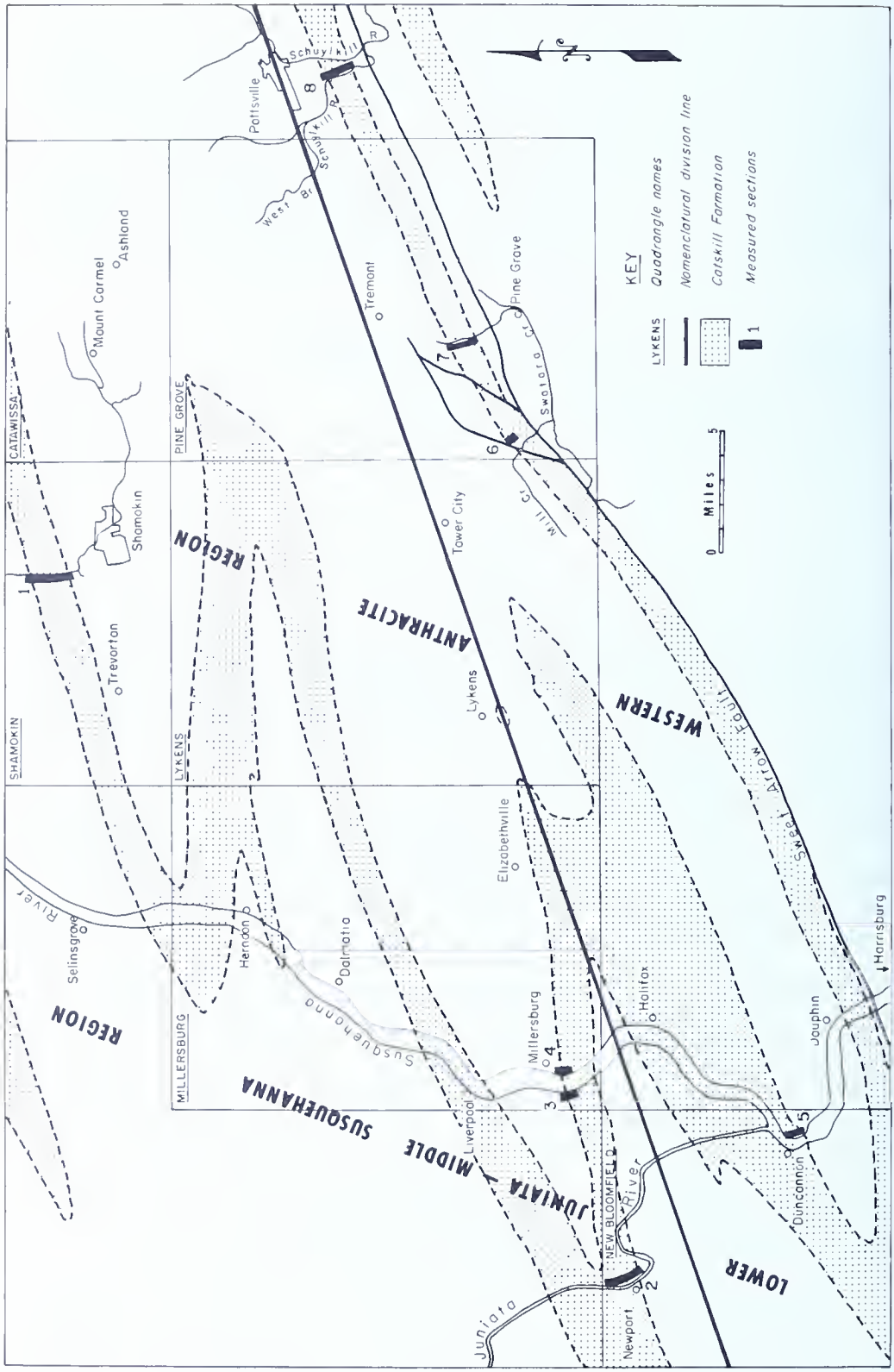


Figure 1. Outcrop of the Catskill Formation in east-central Pennsylvania with location of measured sections. Outlined quadrangles are mapped or in progress.

All the member units interfinger to some degree so that each is mutually correlative, in part, with the underlying or overlying member. Additionaly the Irish Valley interfingers with the upper part of the underlying Trimmers Rock Sandstone.

INTRODUCTION

The Pennsylvania and U.S. Geological Surveys are engaged in mapping extensive areas in east-central Pennsylvania in the lower Juniata-middle Susquehanna region and the adjoining western Anthraçite region (Fig. 1.). Considerable portions of these mutually adjoining areas are underlain by rocks of the Catskill Formation. None of the individual final reports and maps that has or will appear presents an overall view of the lithology and correlation of the various formations in the areas mapped by either Survey. The purpose of the present report is to give a generalized view of the Catskill Formation so that, with respect to this formation, the final reports and maps, which contain a great deal of detailed information, can be related to each other with more ease.

Cooperation between the mapping personnel of the two Surveys is maintained to solve similar problems of mapping and naming formation and member units. With respect to the Catskill Formation essentially complete agreement was reached on the criteria for the physical delineation of the major mappable units. Close, but not complete, agreement was reached in the naming of these major mappable units.

ACKNOWLEDGEMENTS

The present paper was written by Hoskins. The other authors provided detailed descriptions of the eight measured sections and inserted their views on the subdivision of the Catskill Formation and the lithology of the major mappable units. The detailed descriptions (Fig. 2) were generalized by Arndt, Hoskins and Wood.

Section 1 was measured by Arndt, R. S. Jones and R. F. Schryver, sections 2 and 5 by Dyson, section 3 by Hoskins, section 4 by Conlin and L. A. Frakes, and sections 6, 7 and 8 by Wood, Trexler and Thomas Kehn.

PREVIOUS WORK

Miller and Conlin (1959 and 1961) presented a discussion of the Upper Devonian rocks of central Pennsylvania in which they stated the need for a new nomenclatural approach to these rocks. The then existing stratigraphic units, Portage, Chemung and Catskill, had been originally defined partly on paleontologic criteria. These criteria could not be practically applied in field mapping. Only the base of the Portage could be mapped with any degree of accuracy. After their attempts to use the existing stratigraphic names in central Pennsylvania had proved fruitless, they proposed the name Susquehanna Group in order to provide a framework into which

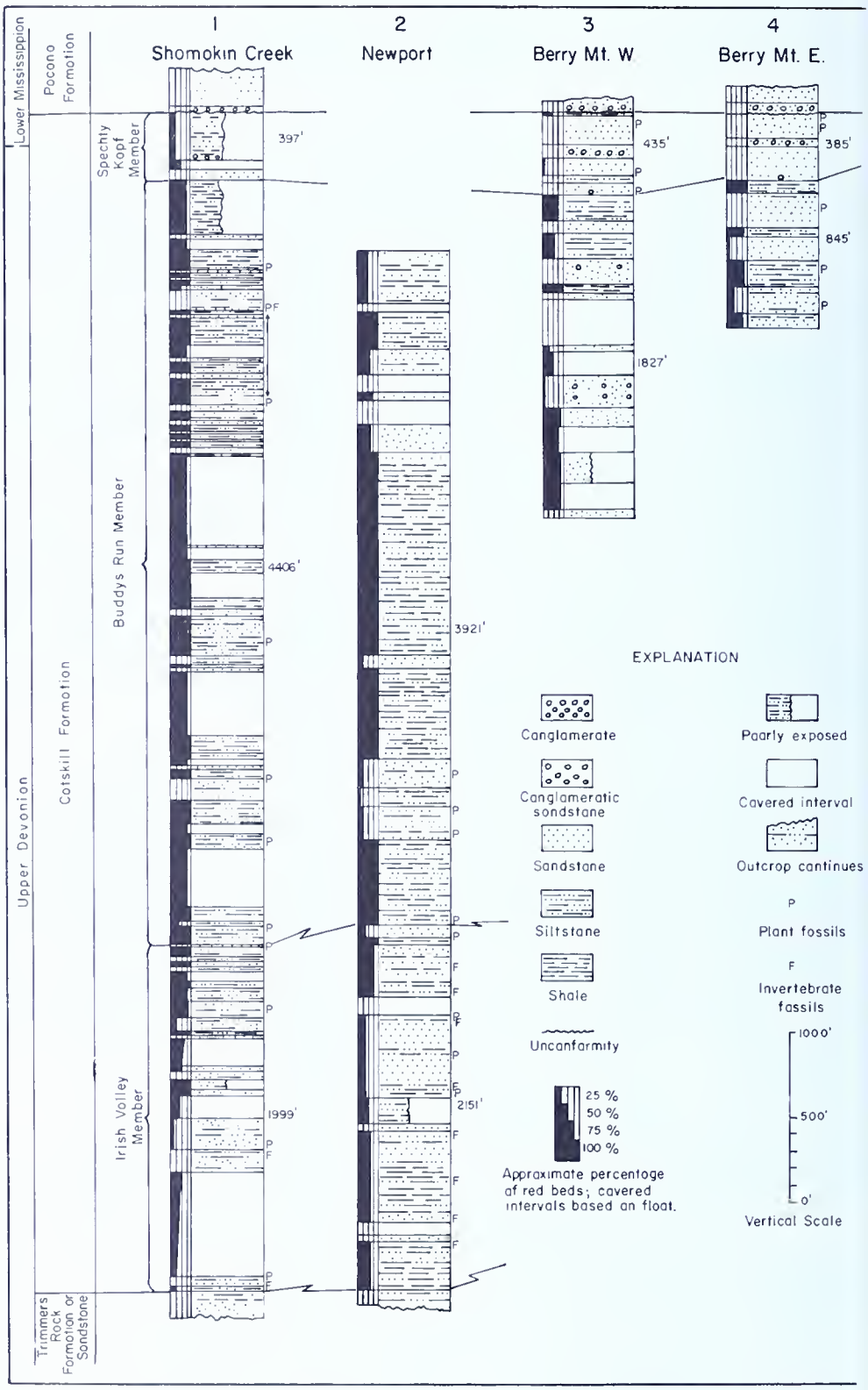
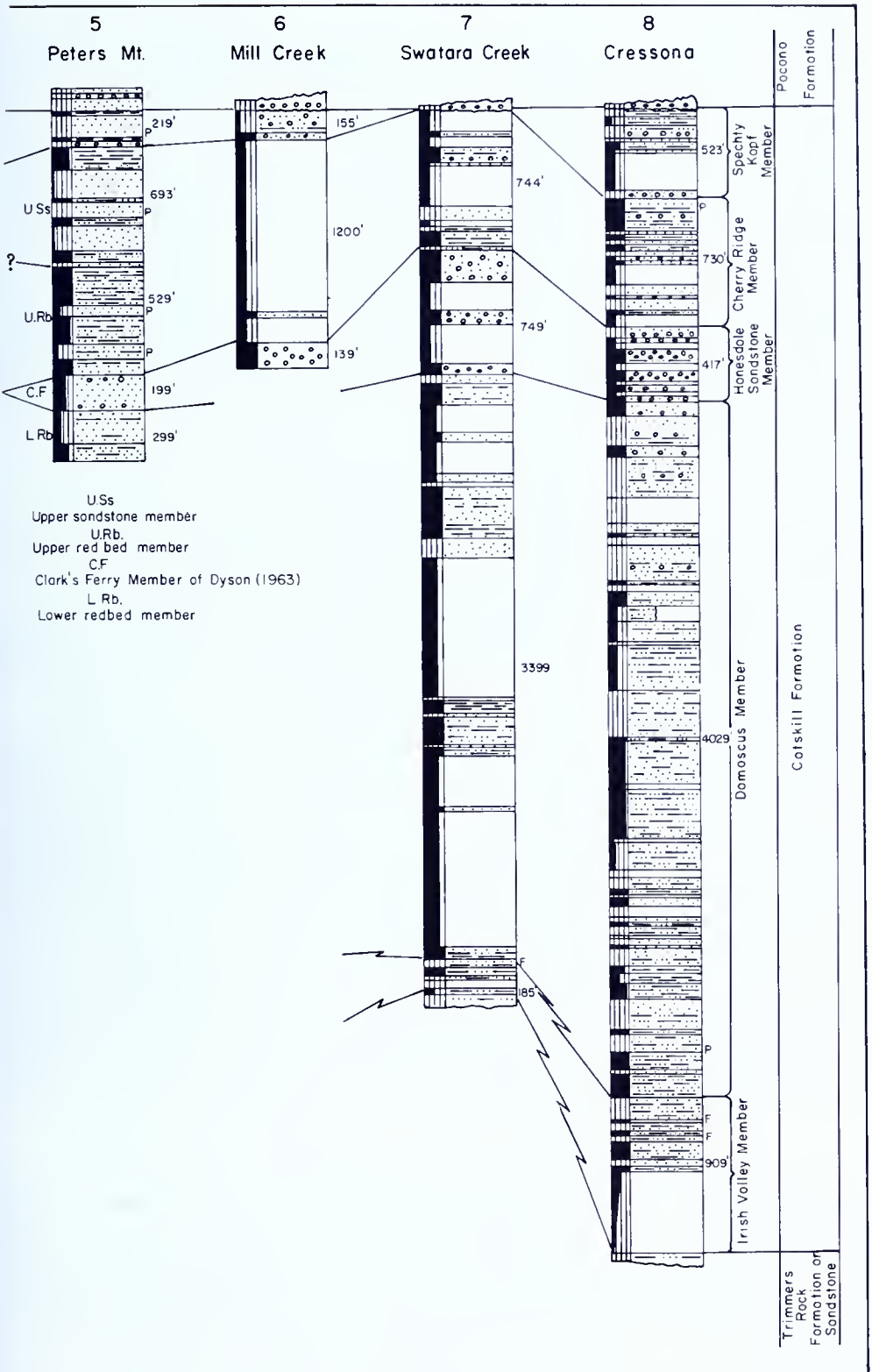


Figure 2. Correlation of measured sections of the Catskill Formation.



U.Ss
Upper sondstone member
U.Rb.
Upper red bed member
C.F
Clark's Ferry Member of Dyson (1963)
L.Rb.
Lower redbed member

could be fitted new or redefined names that would appropiately express known and newly determined details that were resulting from the mapping programs of the two Surveys. This group, as defined, includes "all rocks in Pennsylvania between the top of the red beds of the Catskill Formation and the top of the Hamilton Group" (1961, p. 786). The group contains three fundamental units: marine at the base, transition in the middle, and non-marine at the top. These units are roughly equivalent to the rocks formerly assigned to the Portage, Chemung, and Catskill.

Subsequent to the defining of the Susquehanna Group, Arndt and others (1962) and Trexler and others (1962) defined the Catskill Formation and its member units for the middle Susquehanna and western Anthracite region. Dyson (1963) presented the member definition for the lower Juniata region.

THE SUSQUEHANNA GROUP

The Susquehanna Group in central Pennsylvania is composed of, in descending order, the Catskill, Trimmers Rock, Brallier, and Harrell Formations (Dyson, 1963). In the Lykens and Pine Grove quadrangles, Wood and Trexler include strata which may be equivalent to the Brallier in the basal part of their Trimmers Rock Sandstone. The Trimmers Rock, Brallier and Harrell correspond to the lowest fundamental unit of the Susquehanna Group as defined by Miller and Conlin (1959 and 1961).

The original idea of the three-fold division of the Susquehanna Group carried the implication, although not specifically stated, that each of these three fundamental units would be defined as one or more separate formations. Detailed mapping and examination, however, has shown that the lithologies of the "transition" and "non-marine" units, while sufficiently different to provide convenient mapping, contain repetitions of similar rocks that differ a great deal more from the "marine" formations than they do from each other. Thus it was decided that the similarities of the "transition" and "non-marine" units were best expressed as one formation, the Catskill, with several member units. This definition of the Catskill in the middle Susquehanna and western Anthracite region was presented by Arndt and others (1962).

The Catskill Formation

The Catskill Formation in central Pennsylvania is composed of from 5000 to 9400 feet of Upper Devonian and Lower Mississippian clastic rocks which are mainly grayish-red, ranging from claystone to conglomerate. The formation is unconformably overlain by the Pocono Formation which is a ridge-forming sequence of gray and olive sandstones and conglomerates, and is underlain by the Trimmers Rock consisting of a sequence of olive sandstones, siltstones and shaly claystones that contain

marine fossils and in some areas are characterized by abundant flow rolls and other sedimentary structures.

Northwest of a line (nomenclatural division line) passing near Tremont, Tower City and Halifax (Fig. 1), the Catskill contains three major mappable members; from top to bottom they are: the Spechty Kopf, Buddys Run and Irish Valley Members (Fig. 3). Southeast of the line the Spechty Kopf and Irish Valley Members are also present but the rocks correlative with the Buddys Run Member are divisible into several major mappable units that are accorded separate member status. Near Duncannon in the New Bloomfield quadrangle the correlatives of the Buddys Run are known as the upper sandstone member, upper redbed member, Clark's Ferry Member and lower redbed member (Dyson, 1963). Southeast of Tower City and Tremont in the Lykens and Pine Grove quadrangles the correlatives of the Buddys Run are known as the Cherry Ridge Member, Honesdale Sandstone Member and Damascus Member. As shown on Figure 3, different names are used for the same units in different parts of the area mapped. The reasons for the nomenclatural disagreement will be discussed under the heading *Names correlative with Buddys Run.*

The Catskill Formation as presently defined in central Pennsylvania contains many of the strata formerly included in the Chemung Formation, the entire Catskill Formation of previous workers, and some of the rocks

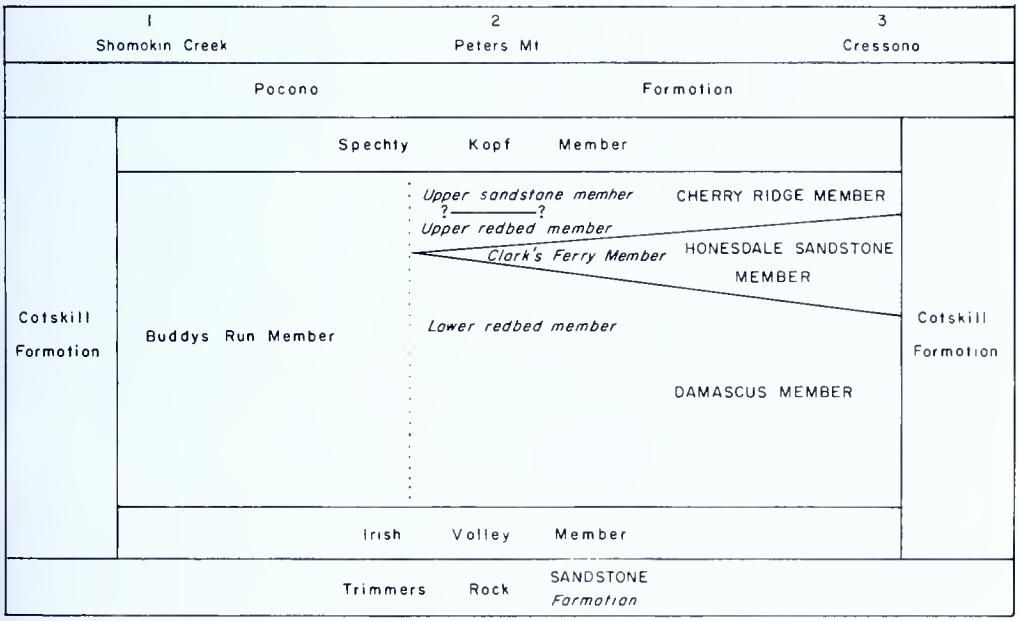


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Figure 3. Current Terminalagy af the Catskill Formatian in central Pennsylvania.

formerly assigned to the Pocono Formation. The present definition of the Catskill for the most part follows that of White (1883, p. 49-67). White recognized for the upper and middle Susquehanna River region a "Pocono-Catskill group, a Catskill series and a Catskill-Chemung group". As near as can be determined, these three units correspond almost exactly to the Spechty Kopf, Buddys Run and Irish Valley Members.

Spechty Kopf Member

The Spechty Kopf Member was named by Trexler and others (1962, p. C36) and is the uppermost member of the Catskill Formation. The unit was informally called "gray member of the Catskill Formation" by Trexler and others (1961) who noted that the unit was the same as White's "Pocono-Catskill group".

The member unconformably underlies the Pocono Formation and with the Pocono supports a high ridge. The basal conglomeratic portion of the Pocono is at the ridge crest or near the crest on the dip slope. The Spechty Kopf occupies the crest and the upper part of the scarp slope. In a few places, including the type area, the lower part of the Spechty Kopf forms a separate ridge. Few extensive outcrops of the member can be seen because of the large amount of Pocono-Catskill scree that covers the ridge slopes. The Spechty Kopf, however, contains a 2- to as much as 100-foot conglomeratic unit near its base that is semicontinuous in outcrop and which affords an excellent key bed that is used to trace the member.

The Spechty Kopf is composed primarily of fine- to medium-grained, light- to dark-gray and greenish- to dark-greenish-gray, cross-bedded, medium- to thick bedded, quartzitic sandstone. The member also contains appreciable amounts of olive-gray to dark-gray and grayish-red siltstone and very-fine-grained sandstone, and light- to greenish-gray, coarse- to very-coarse- grained sandstone. Minor, but very important lithologies are light- to medium-light-gray, sandy conglomerate and conglomeratic sandstone containing from 2 to 30 percent of quartz and chert pebbles and cobbles up to 3 inches in diameter. Most pebbles fall in the one-half to 1-inch class. Zones of siderite nodules and coalified plant remains are present in many of the siltstone and finer sandstone strata. Carbonaceous shale and thin coal beds, 1 to 2 inches thick, occur in some outcrops. Locally in the Lykens and Pine Grove quadrangles a coal bed ranging up to 3 feet in thickness was mined. Thickness irregularities and high ash content prevented extensive commercial exploitation, however. In many respects the major lithology of the unit is very similar to that of portions of the overlying Pocono Formation. For this reason these rocks were included with the Pocono Formation by previous workers. Of these previous workers only White (1883) seems to have recognized their affinities with the rest of the Catskill Formation.

In the type area of the Spechty Kopf, a few miles south of Lykens near

the southern border of the Lykens quadrangle, the member reaches its maximum thickness of 2400 feet. Over most of the area mapped, however, the unit is from 200 to 500 feet thick. At the type locality a lower sandy and conglomeratic part is overlain by considerable amounts of grayish-red siltstone and sandstone interbedded with light- to olive-gray siltstones and fine- to medium-grained sandstones. West and south of the type area along the flanks of the Joliet anticline (Trexler and others, 1961, Fig. 38.2) the upper 1900 feet of the Spechty Kopf is successively beveled by the pre-Pocono erosion surface. The lower conglomeratic part of the Spechty Kopf has been traced nearly everywhere in the area of the present investigation. In a few localities, however, as along Second Mountain in the southern outcrop belt of the Pine Grove quadrangle, the Spechty Kopf is missing and the Pocono rests on the Cherry Ridge Member.

Dyson (1963) did not map the Spechty Kopf Member in the northern half of the New Bloomfield quadrangle. He recognized, however, that the lower 200 feet of strata included by him in the Pocono is very similar in lithology to the Spechty Kopf of other areas. In preparing Figure 2 Hoskins took the liberty of designating these 200 feet of predominantly gray sandstone in the Catskill Formation as the Spechty Kopf Member. This action is provisional and is subject to revision when detailed mapping between the Lykens and New Bloomfield quadrangles is completed. It is the opinion of Hoskins, however, that the similarity of the Spechty Kopf as exposed in the Berry Mountain sections to the strata in question at Peters Mountain, amply warrants this correlation.

Trexler and others (1962, p. C37), on the basis of a small fossil flora, dated the Spechty Kopf as Late Devonian and Early Mississippian in age. Read (1955, p. 8) noted *Adiantites,* an Early Mississippian fossil, in a coaly unit in the Berry Mountain East section. This coaly unit occurs a few feet below the conglomerate in the middle of the Spechty Kopf.

Complete exposures of the Spechty Kopf occur at the two Berry Mountain sections and the Peters Mountain section.

The uppermost contact of the member is located at the bottom of the basal conglomerate of the Pocono Formation. This conglomerate is easily traced in most areas and variably overlies unconformably green, gray and red beds of the Spechty Kopf. The lower contact of the Spechty Kopf is placed at the horizon where the dominant gray sandstones and conglomerates in the lower part of the member are replaced by red and gray siltstones and sandstones of the underlying Buddys Run, Cherry Ridge or upper sandstone members.

Buddys Run Member

The Buddys Run Member was the name given by Arndt and others (1962, p. C35) to the mappable unit that constitutes two-thirds of the Catskill Formation below the Spechty Kopf Member in the area northwest

of the nomenclatural division line (Fig. 1). This member corresponds to the strata that generally have been considered the Catskill Formation by previous workers.

The member underlies the major portion of the scarp slopes of the ridges which are held up by the resistant Pocono Formation and the Spechty Kopf Member. The Buddys Run also underlies much of the lower land that flanks the Pocono ridges. The upper part of the member is invariably covered by thick Pocono and Spechty Kopf scree and is rarely exposed except in water gaps. The lower part of the member is moderately well exposed in numerous small outcrops along streams and country roads. Where cultivation has removed the thick forest cover from the lower part of the member, numerous submember units are mappable for limited distances. The Buddys Run Member forms a rolling upland topography that grades into the steep slopes of the nearby Pocono-Spechty Kopf ridges.

Grayish-red rocks make up approximately 75 percent of the Buddys Run Member. The lower two-thirds of the unit contains up to 90 percent of red beds while the upper one-third contains from 50 to 60 percent red beds. This preponderance of red over other colors distinguishes the Buddys Run from the overlying and underlying members.

The major rock types of the member are grayish-red, hackly weathering or fissile claystone and micaceous siltstone. Interbedded with the claystone and siltstone is very fine- to medium-grained quartzitic sandstone which is grayish-red to brownish-gray, light- to olive-gray and greenish- to dark-greenish-gray. Medium- to very coarse-grained, light- to olive-gray sandstone occurs commonly near the top of the member, and less commonly in lower portions. Several of the very coarse-grained sandstone beds locally contain discontinuous lenses of pebbles, forming minor beds of conglomerate and conglomeratic sandstone. Bedding ranges from thin- to thick-bedded with considerable cross-bedding.

Dyson (1963) discusses the excellently exposed section at Newport (Fig. 2, section 2) and notes the striking repetition or cyclicity of lithologic types. The cycles are most pronounced in the lower part of the Buddys Run, but also occur in the underlying Irish Valley Member. As described by Dyson, these consist as follows:

> "of a basal unit of gray sandstone resting on an eroded red shale surface. This sandstone grades upward into finer grained reddish sandstone which in turn gives way first to red siltstone and finally shale at the top. Any one of the units may be missing. In a number of the cycles the gray sandstone grades upward into olive-gray siltstone and shale and then into red shale. The basal sandstone varies in thickness from a couple of inches to 30 or 40 feet. Plant fragments and shale pebbles occur at the base of some of these sandstone beds."

The Buddys Run Member in the mapped area ranges in thickness from 3100 to 4800 feet but generally is in the range of 4000 to 4500 feet. Plant fragments are the only identifiable definite fossil remains. A few beds con-

tain what appears to be very poorly preserved brachiopods or pelecypods but phyletic identification of these is uncertain.

The Buddys Run is moderately well exposed (65 percent) at its type section (Fig. 2, section 1). A better exposed section lacking the upper 300 to 500 feet is at Newport (Fig. 2, section 2).

The contact between the Buddys Run and the overlying Spechty Kopf Member is placed where the predominant red shales and sandstones of the lower unit are replaced by predominant gray sandstones and conglomerates of the upper unit. In some areas this contact is a few feet below a conglomerate unit in the Spechty Kopf. The base of the Buddys Run is mapped where the dominantly red-bed sequence comprising the main body of the Catskill Formation is, in the lower part, noticeably replaced by olive and gray beds. This contact is in a red and gray intertonguing sequence and is drawn stratigraphically higher or lower in different quadrangles depending on the vertical interfingering of red and non-red beds when mapped from one quadrangle to another.

Names correlative with Buddys Run

Southeast of the nomenclatural division line (Fig. 1) the rocks correlative with, and lithologically similar to, the Buddys Run Member contain a major, resistant, ridge-forming sandstone and conglomerate unit that is clearly mappable as a separate member. The occurrence of this resistant unit divides the strata into three distinctive units, a basically red, non-resistant sequence at the top, the red and gray resistant unit and, at the base, another basically red, non-resistant sequence. Were it not for the resistant unit the upper and lower sequences would be mapped as the Buddys Run Member.

The three distinctive units were called in descending order, the Cherry Ridge red beds, Honesdale sandstone and Damascus red beds by Willard (1936, p. 577-585) based on a correlation between the type areas of these units on the Pocono Plateau and exposures along the Lehigh River in eastern Pennsylvania. Klemic and others (in press, U.S. Geological Survey) after an extensive reconnaissance on the Pocono Plateau and detailed mapping in the Lehigh River Valley Region accepted Willard's names. Arndt and others (1962, p. C32) also of the U.S. Geological Survey, working to the west of Klemic in the same belt of outcrop concur in this usage and therefore adopted these stratigraphic names for the Lykens and Pine Grove quadrangles.

Reasonable doubt exists, however, on the part of the Pennsylvania Geological Survey as to the validity of recognition of the Cherry Ridge, Honesdale and Damascus at the Lehigh River. It is felt that the well-defined "Honesdale Sandstone group", 90 feet thick, at its type section at Honesdale, Pennsylvania (White, 1881, p. 186) may not be traceable into,

or definitely correlative with, the approximately 1000 feet of resistant sandstone exposed along the Lehigh River that was tentatively called Honesdale by I. C. White. While (1882, p. 94) pointedly states "the beds on the Lehigh River included above under the head of *Cherry Ridge red shale* (1157′) and *Honesdale sandstone group* (987′) have become so thickened and changed in character. . .that their identification, except in the most general way with these beds in Wayne County, would be wholly problematical."

Therefore, the Pennsylvania Geological Survey prefers not to use Cherry Ridge, Honesdale and Damascus, except in the immediate area of the type sections of these units on the Pocono Plateau, until further mapping establishes or disproves the correlations accepted by Willard (1936) and members of the U. S. Geological Survey. For equivalent rocks the Pennsylvania Geological Survey accepts the terminology of Dyson (1963) indicated in Fig. 3 under the Peters Mountain heading.

The name Clark's Ferry Member was introduced by Dyson in the New Bloomfield quadrangle (1963) in preference to the name Honesdale and is accepted by the Pennsylvania Geological Survey because it is felt that the Honesdale as described by Willard (1936), Klemic and others (in press), and Arndt and others (1962) may not be applicable for the middle Susquehanna region. The name was chosen from Clark's Ferry near where the unit is completely exposed.

The units above and below the Clark's Ferry were not formally named by Dyson (1963) because: 1. it is expected that much of the Damascus Member at its type area may prove correlative with the lower red bed member and only a redefinition of the name Damascus would be required and, 2. the two member units correlative with the Cherry Ridge may not prove mappable beyond a small area and practically would be best treated as submembers of one member. In that case one new name would be desirable.

The upper sandstone and upper red bed members are discussed below under the heading Cherry Ridge Member, the Clark's Ferry under Clark's Ferry or Honesdale Sandstone Member and lower red bed member under Damascus Member for the practical purpose of nonrepetition. Application of the various stratigraphic names by the two Surveys is clearly indicated on Fig. 3.

Cherry Ridge Member

The Cherry Ridge Member underlies the swale between the adjacent ridges held up by the Pocono or Spechty Kopf and the Clark's Ferry or Honesdale units. The member extends up onto the scarp slope of the Pocono ridge. Outcrops of the member are rare because of the scree from the adjacent resistant ridges.

Siltstone and sandstone each make up about 50 percent of the member. The sandstone ranges from very fine- to very coarse-grained but most is fine- to medium-grained. Grayish-red and brownish-gray rocks predominate, but considerable amounts of gray, olive-gray and greenish-gray rock are present. Minor parts of the unit are made up of weakly cemented conglomeratic sandstone with pebbles up to 1 inch in diameter. Bedding ranges from thin- to thick-bedded. Cross-bedding, while present, is not a characteristic feature. The unit differs in no important respect from the upper part of the Buddys Run Member.

In the Duncannon area rocks equivalent to the Cherry Ridge are mapped as two members (Dyson, 1963). Lithologically these members are similar to the Cherry Ridge of the Lykens and Pine Grove quadrangles. They differ, however, one from the other in the following respect: The upper sandstone member consists of about 55 percent non-red sandstone with interbeds of red shale and siltstone; the upper red bed member consists of about 80 percent red shale, siltstone and sandstone and 20 percent non-red sandstone. Cyclic repetition of lithologies is present in the lower 15 percent of the upper sandstone member and throughout the upper red bed member. The lithologies of these two units are well shown in the Peters Mountain exposure (Fig. 2, section 5).

Carbonized plant remains are present in a few beds of the Cherry Ridge unit. The member ranges in thickness from 800 to 1200 feet in the Lykens and Pine Grove quadrangles. At Peters Mountain the upper sandstone member is 693 feet thick and the upper red bed member is 629 feet thick.

The upper contact of the Cherry Ridge unit is as described for the upper contact of the Buddys Run Member, except in the outcrop belt north of Pine Grove where erosion has removed the Spechty Kopf Member and the basal conglomerate of the Pocono Formation rests directly on the non-resistant red beds of the Cherry Ridge. The basal contact of the Cherry Ridge unit is mapped at the top of the resistant conglomerate and sandstone of the underlying Clark's Ferry or Honesdale Sandstone Member.

Clark's Ferry or Honesdale Sandstone Member

The Clark's Ferry Member generally underlies a subsidiary ridge or break-in-slope on or near the scarp slope of the adjacent Pocono or Spechty Kopf ridges. In some areas, however, the member underlies a ridge which is totally separate from the higher ridges. Outcrops are common along the ridge crest where the resistant conglomeratic units form rock walls up to 50 feet high. Outcrops of the non-conglomeratic portion of the unit are rare.

The Clark's Ferry Member, as exposed at the type section on Peters Mountain (Fig. 2, section 5) consists of 80 percent of medium- to very coarse-grained, gray to grayish-red sandstone with scattered quartz peb-

bles up to three-quarters of an inch in diameter in the upper and lower 30 feet. Interbedded with the coarser sandstone are grayish-red siltstone and fine-grained sandstone which make up 20 percent of the unit.

In the Lykens and Pine Grove quadrangles the Honesdale Sandstone Member is made up of conglomerate, and conglomeratic and coarse sandstone with a minor amount of finer grained clastic rocks. There the rocks are generally pale red, pale brown, or grayish red. The upper and lower portions of the Honesdale in the Pine Grove-Lykens area are very conglomeratic and form conspicuous exposures.

The Clark's Ferry or Honesdale Sandstone Member varies markedly in thickness over the mapped area from 0 to 725 feet. Fossils have not been found in the unit.

In addition to the Peters Mountain section the member is well exposed at Cressona (Fig. 2, section 8) and south of Pottsville.

The upper contact of the Clark's Ferry or Honesdale Sandstone Member is placed at the top of the uppermost resistant coarse sandstone or conglomeratic sandstone overlain by non-resistant red beds of the Cherry Ridge unit. The lower contact is at the base of resistant sandstone and conglomerate below which are much less resistant red beds.

Damascus Member

The Damascus Member as defined by Arndt and others (1962) underlies the lower part of the ridge and slope held up by the Clark's Ferry-Honesdale and much of the adjacent cultivated rolling upland.

Lithologically this unit is very similar to the lower part of the Buddys Run Member and consists for the most part of grayish-red shale, siltstone and fine-grained sandstone with minor amounts of interbedded non-red rocks ranging up to very coarse-grained sandstone. Red beds generally make up 75 percent of the member. Toward the east in the Pine Grove quadrangle and near Cressona the amount of red beds drops to 50 and 40 percent.

Plant fragments occur in the Damascus Member in many of the finer grained sandstone strata. In the Pine Grove-Lykens area the thickness of the member ranges from 3400 to 4000 feet. Dyson (1963) estimates that the correlative lower red bed member is about 3000 to 3300 feet thick in the Duncannon area. The Damascus Member is well exposed only at the Cressona section and south of Pottsville.

The upper contact of the Damascus Member is placed at the base of the lowest ridge-forming sandstone and conglomerate of the Clark's Ferry or Honesdale. The basal contact, like the base of the Buddys Run Member, is difficult to place because of the intertonguing with the underlying Irish Valley Member. This contact is located where the thick red bed sequence comprising the Damascus is noticeably replaced by olive and gray beds alternating with thin red beds.

Irish Valley Member

The Irish Valley Member was named by Arndt and others (1962, p. C35) for the varicolored unit that makes up the lower part of the Catskill Formation. It occupies as much as one-third of the total formation. The member corresponds to the Catskill-Chemung group of White (1883) and was mapped by Miller (1961) as the "Catskill-Fort Littleton Transition Beds". Miller and Conlin (1961) discuss these strata under the heading "transition unit".

Irish Valley Member consists of many alternations, from few inches to many feet, of red and non-red strata. The rocks are mainly shale, siltstone and very fine- to fine-grained sandstone ranging in color from grayish-red to brownish-gray, light- to dark-gray, yellowish-olive to olive-gray and dusky-yellow, and greenish- to dark-greenish-gray. The percentage of non-red strata increases downward in the section to the basal contact. Many of the thin, distinctively colored units are easily traced in cultivated areas.

Fossils, both plant and marine invertebrate, are present in the Irish Valley Member. Dyson (1963) reports several horizons containing brachiopods, mainly of the genus *Platyrachella.* Plant fossils are present throughout much of the member.

The Irish Valley thickens northeastward and northwestward from 185 feet north of Pine Grove (Fig 2, section 7) to 900 feet at Cressona (section 8), 2,000 feet at Shamokin Creek (section 1), and 2,150 feet at Newport (section 2). Throughout much of the area northwest of the nomenclatural division line (Fig 1) the Irish Valley is from 1800 to 2200 feet thick. South of the Sweet Arrow Fault, in the southernmost Catskill outcrop belt of the Pine Grove quadrangle the Irish Valley is 800 to 900 feet thick. Wood considers this apparent thickening to the southeast from the Swatara Creek section to be anomalous and attributes it to major slip on the Sweet Arrow Fault.

The best exposure of the Irish Valley Member is at the Newport section. The member is about 50 percent exposed at the type section along Shamokin Creek.

Both the upper and lower contacts of this member are in intertonguing sequences. The scale of the intertonguing is sufficiently large so that in some areas it can be shown on 1/24,000 scale maps. The upper contact is at the base of the first dominantly red unit above the alternating thin, red and non-red strata. The basal contact, which is also the basal contact of the Catskill Formation, is at the base of the lowest grayish-red bed. In some areas this contact is difficult to determine because brownish-gray beds, somewhat similar to the grayish-red beds, may occur below the lowest obvious red unit. These brownish-gray beds are similar to brownish-gray beds above the lowest red bed but are usually associated with flow rolls and other sedimentary features characteristic of the under-

lying Trimmers Rock Formation or Sandstone and are therefore included in that formation.

Independent mapping by different field parties in mutually overlapping and adjoining areas has demonstrated the practicality and reliability of the basal contact of the Catskill Formation as defined above.

Both the lower and upper contacts of the Irish Valley rise in the stratigraphic section westward. Thus part, if not all, of this member in the Pine Grove quadrangle may be equivalent in age to part of the Trimmers Rock of the Susquehanna River area. Also, part of the Irish Valley of the Susquehanna River area may be equivalent in age to the lower part of the Damascus of the Pine Grove area.

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APPENDIX

Location of Sections on Figure 2

1. Shamokin Creek section; west side of Shamokin Creek along the Reading railroad 1½ to 3¼ miles north of Shamokin, Shamokin 15-minute quadrangle. Type section of Buddys Run and Irish Valley Members.
2. Newport section; east side of Juniata River along U. S. Routes 22-322 from 100 yards south of the Newport bridge north to the axis of the Buffalo-Berry Mountain syncline, New Bloomfield and Millerstown 15-minute quadrangles.
3. Berry Mountain West section; west side of Susquehanna River gap in Berry Mountain along U. S. Route 11 and 15, 3½ miles south of Liverpool, Millersburg 15-minute quadrangle.
4. Berry Mountain East section; east side of Susquehanna River gap in Berry Mountain along Pennsylvania Route 147, 1 mile south of Millersburg, Millersburg 15-minute quadrangle.
5. Peters Mountain section; east side of Susquehanna River gap in Peters Mountain along Pennsylvania Railroad and U. S. Routes 22-322, three-fifths of a mile south of the Clark's Ferry Bridge, New Bloomfield 15-minute quadrangle. Type section of the Clark's Ferry Member. Dyson (1963).
6. Mill Creek section; east side of Mill Creek gap in Second Mountain along abandoned railroad about one-tenth of a mile south of the Lebanon Dam, Pine Grove 15-minute quadrangle.
7. Swatara Creek section; west side of Swatara Creek along the Reading Railroad from 1.6 miles north of Pine Grove to .6 miles north of Ravine, Pine Grove 15-minute quadrangle. The Cherry Ridge Member is exposed on the east side of the Swatara Creek gap in Second Mountain.
8. Cressona section; east side of the West Branch Schuylkill River gap in Second Mountain along the paved road leading from Beckville to Mt. Carbon, Pottsville 7½-minute quadrangle.

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Interpretation of Primary Bedding Structures in Mississippian and Upper Devonian Rocks of Southeastern Somerset County, Pennsylvania[1]

ABSTRACT

In southeastern Somerset County, along the Deer Park anticline, primary bedding structures were studied in an attempt to determine current directions present during deposition of the Mississippian and Devonian rocks cropping out in the area. Specific formations studied included the Jennings and Catskill Formations of the Upper Devonian System and the Pocono Formation of the Mississippian System.

It is generally recognized that primary bedding structures with vector properties such as cross-stratification, oscillation ripple marks, and current and flute casts give good indication of direction of flow of the depositional media. Such indications are valid only if the structures are studied with the use of acceptable statistical procedures. Cross-stratification proved to be the most abundant primary bedding structure present, but other structures such as oscillation ripple marks, groove casts and flute casts were observed and recorded where found.

Results of the study can be tabulated as follows:

Formation	Predominate sandstone type where structures were found	Vector mean of cross-stratification
Jennings (Chemung)	feldspathic sandstones and orthoquartzites	277°
Catskill	feldspathic graywackes and feldspathic sandstones	311°
Pocono	variable	292°

The significant values of the vector means shown are all 99.0th level or greater.

Oscillation ripple marks and groove casts are abundant in the Jennings and Catskill Formations respectively. Vector analysis of these structures favorably supported results of the cross-stratification analysis.

Results of primary bedding structure analysis along with detailed lithologic descriptions of the rocks studied lead to reconstruction of provenance and depositional environments.

[1]Originally submitted, November 1960, to the Graduate Faculty in the Division of the Natural Sciences, University of Pittsburgh, in partial fulfillment of the requirements for the degree of Master of Science. Herein submitted under the auspices of the Northern Appalachian Basin Geological Society.

These cross-stratification studies over a rather small area are in good agreement with other regional studies of correlative formations in the Appalachian Basin. It is suggested that carefully made local paleocurrent studies in one formation can predict the regional paleocurrent trends of that formation. This procedure can be expected to work well in formations whose sandstones are widespread and of consistent lithology.

INTRODUCTION

Statement of Problem

In recent years studies and interpretations of primary bedding structures have become an important tool used in reconstruction of sedimentary paleoenvironments. Such studies of primary bedding structures serve to determine paleocurrent and paleoslope directions, and from these, the direction and consistency of direction through geologic time, of the source of the sediments are inferred. These studies cannot locate the exact position of the source area and/or its distance from the site of deposition. This report presents the results of measurement, analysis and interpretations of primary bedding structures studies, but little attempt has been made to reconstruct a complete paleoenvironment of that part of the Appalachian Basin studied. Details of petrography, stratigraphy, and paleontology are introduced herein only to support primary bedding structure interpretations.

Work was conducted on rocks of Upper Devonian and Mississippian ages in a very small part of the Appalachian Basin. Results of this report are compared with those of other reports that have dealt with studies of few rock units over wide areas of the Appalachian Basin. It is hoped that this report shows that a small local study employing accepted statistical methods can provide a key to predicting more regional paleocurrent trends in certain formations.

The writer is grateful to Dr. N. K. Flint, Associate Professor of Geology at the University of Pittsburgh, who suggested the problem, and guided the work through its various phases.

Appreciation is also extended to Dr. Louis Rieg of Gulf Research and Development Company for advice on statistical treatment of data and to Dr. T. V. Buckwalter, Associate Professor of Geology at the University of Pittsburgh, who critically read this report and offered helpful suggestions.

Location of Area

The area encompassed by this study covers approximately 200 square miles and lies in the extreme southeastern part of Somerset County, Pennsylvania, extending slightly into Bedford County, Pennsylvania. The area is bordered on the northwest by Allegheny Mountain, on the north by 40°00′ north latitude, on the east by 78°45′ west longitude, and on the south by the Pennsylvania-Maryland border. The majority of the area

lies within the Berlin quadrangle (15′), but it also extends into parts of Meyersdale (15′), Avilton (7½′), Frostburg (7½′), and Cumberland (7½′) quadrangles.

General Geology of Area

Somerset County lies along the eastern edge of the Allegheny Plateau portion of the Appalachian Plateaus in the northcentral part of the Appalachian geosyncline. The rocks exposed in southeastern Somerset County range in age from Lower Devonian (the Helderberg limestone) to upper Pennsylvanian (the sandstone immediately above the Pittsburgh coal of the lower Monongahela Group) (See Figs. 1 and 2).

Detailed studies of primary bedding structures were made on the Jennings ("Chemung"), Catskill, and Pocono Formations. Scarcity of outcrops prevented detailed study and analysis of primary bedding structures in the Pennsylvanian sediments, the Mauch Chunk Formation, the Loyalhanna Limestone and in the Devonian sediments below the Jennings Formation.

The structure of the area is dominated by a large breached anticline and the nose of a plunging syncline. The Deer Park anticline, trending N.30°E, has been breached completely by erosion, and the remaining scarps or flanks of the anticline are now seven miles apart (Fig. 1). Allegheny Mountain is a prominent ridge on the northwestern flank, and Little and Big Savage Mountains are prominent ridges on the southeastern flank.

The Wellersburg syncline lies in the extreme southeast corner of the area under study. It is an asymmetrical syncline which plunges to the southwest. On the northwest flank of the syncline the rocks dip about 20°, whereas on the southeast flank the strata are close to vertical.

A part of the rocks exposed in the center of the Deer Park anticline is of the Upper Devonian Jennings Formation. The flank scarps are supported by resistant Pottsville and Pocono sandstones of the Pennsylvanian and Mississippian Systems.

FIELD AND LABORATORY PROCEDURES

Introduction

The procedure for determining paleocurrent trends in any given formation by the use of primary bedding structures is to measure the azimuth of these structures at different outcrops over an extensive area. These measurements then must be manipulated both mathematically and statistically to determine the average paleocurrent direction, the variance of the readings, and the significance of the results. The average of all readings of cross-strata is inferred to be the direction of the regional slope over which

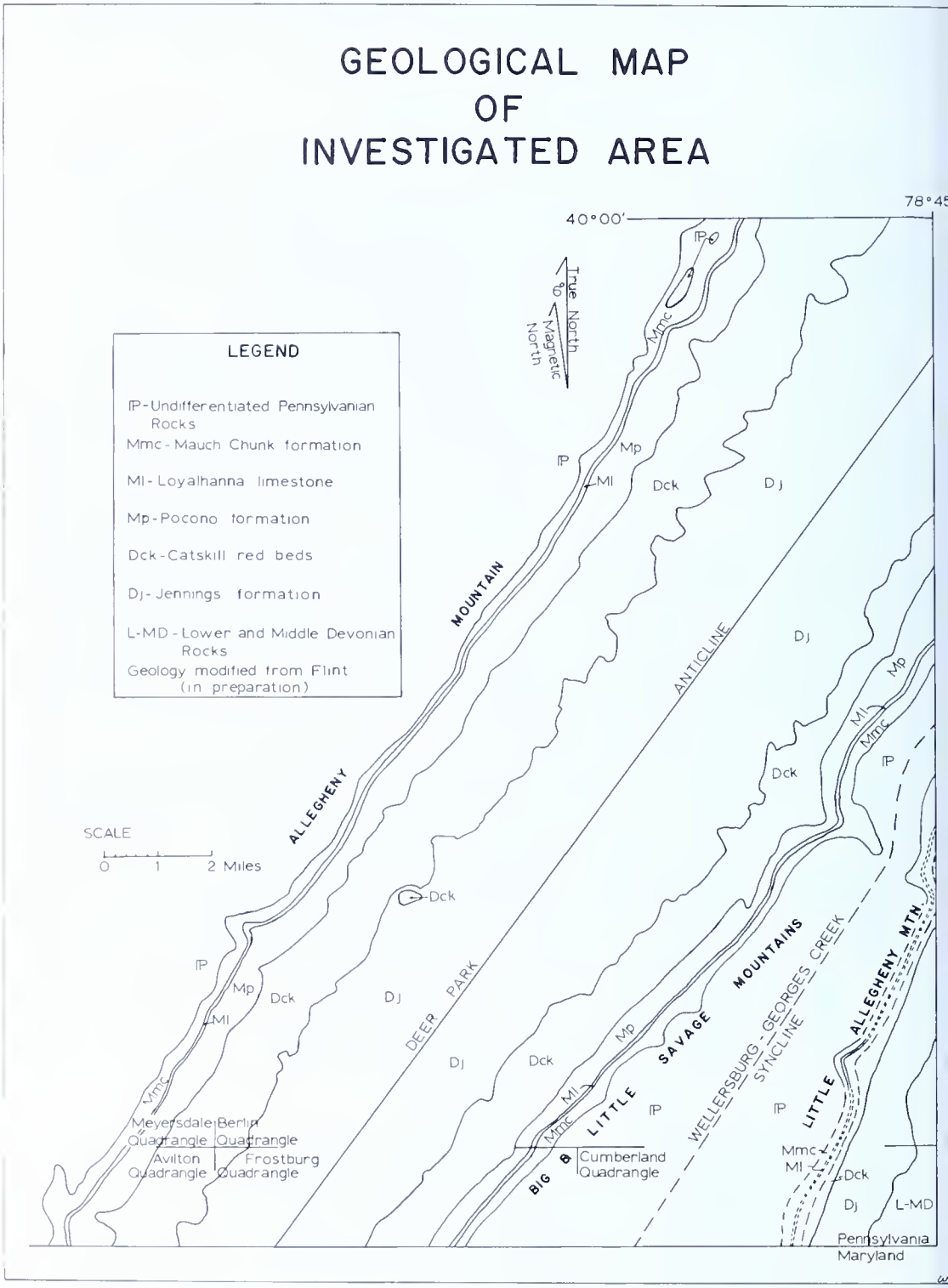
GEOLOGICAL MAP
OF
INVESTIGATED AREA
LEGEND
IP-Undifferentiated Pennsylvanian Rocks
Mmc-Mauch Chunk formation
Ml-Loyalhanna limestone
Mp-Pocono formation
Dck-Catskill red beds
Dj-Jennings formation
L-MD-Lower and Middle Devonian Rocks
Geology modified from Flint (in preparation)
SCALE
0 1 2 Miles
True North
Magnetic North
40°00'
78°45
ALLEGHENY MOUNTAIN
DEER PARK ANTICLINE
SAVAGE MOUNTAINS
WELLERSBURG-GEORGES CREEK SYNCLINE
LITTLE ALLEGHENY MTN.
LITTLE & BIG
IP
Mp
Ml
Mmc
Dck
Dj
L-MD
Meyersdale Quadrangle
Berlin Quadrangle
Avilton Quadrangle
Frostburg Quadrangle
Cumberland Quadrangle
Pennsylvania
Maryland

Figure 1.

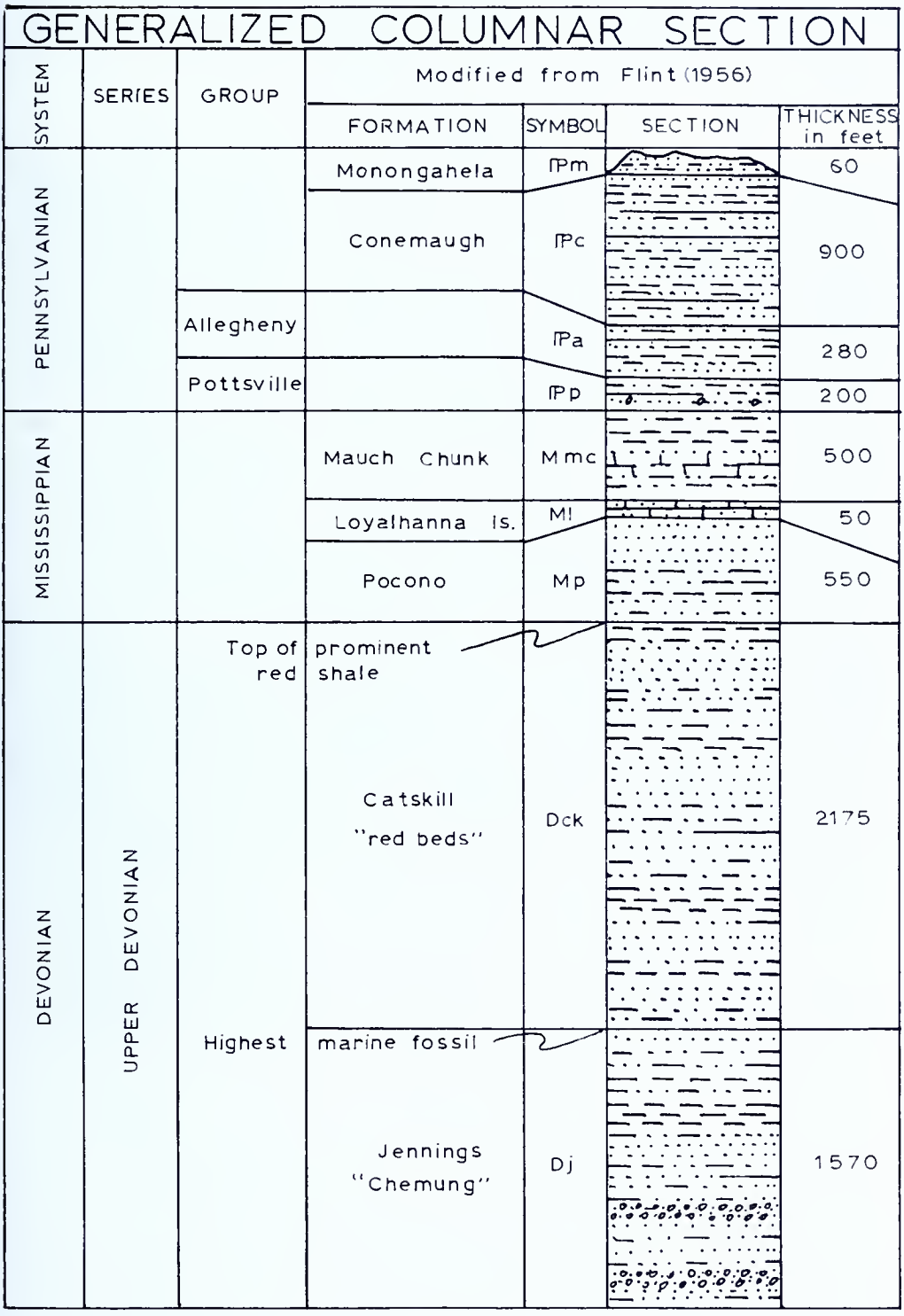
GENERALIZED COLUMNAR SECTION
Modified from Flint (1956)
SYSTEM
SERIES
GROUP
FORMATION
SYMBOL
SECTION
THICKNESS in feet
PENNSYLVANIAN
MISSISSIPPIAN
DEVONIAN
UPPER DEVONIAN
Monongahela
IPm
60
Conemaugh
IPc
900
Allegheny
IPa
280
Pottsville
IPp
200
Mauch Chunk
Mmc
500
Loyalhanna ls.
Ml
50
Pocono
Mp
550
Top of red
prominent shale
Catskill "red beds"
Dck
2175
Highest
marine fossil
Jennings "Chemung"
Dj
1570

Figure 2.

the streams flowed; the opposite direction is inferred to be that of the source area. This general relationship has been disproved in some places of modern deposition, but most geologists consider it valid in most places.

Field Methods

The field work on which this report is based was performed in the late spring and early summer of 1960. True strike and dip measurements were made with a Brunton compass and dip direction indicator (Pryor, 1958). An attempt was made to keep measurements evenly spaced so as not to overbalance the readings of any one area. A hierarchical or multi-level sampling procedure similar to that used by Potter and others (1958) was chosen. Three levels of subsampling were used for measuring cross-stratification. Outcrop belts were divided into one mile intervals—one outcrop per interval, two sedimentary units per outcrop, and one foreset stratum per sedimentation unit. In short, two measurements of cross-strata were made every mile along the outcrop belt. At some outcrops only one measurement could be made; this was offset by taking three readings at a nearby outcrop of the same formation. Selection of the sedimentary units and the foreset strata to be measured within an outcrop was based on best definition and accessibility, a method providing maximum economy of time while in the field and yet resulting in sufficient accuracy. This system proved satisfactory for measurements in the Catskill Formation and moderately successful for the Jennings Formation. Because of a scarcity of outcrops of the Pocono Formation, this procedure could not be used, and measurements were taken at nearly all observed outcrops that displayed cross-stratification. A total of 93 outcrops were measured and sampled, and 180 cross-strata azimuth readings were recorded, an average of 1.93 readings per outcrop.

Because occurrences of ripple and sole marks are sporadic, no sampling pattern could be used in their measurement, nor could they be analyzed correctly with statistics. Only circular histograms were made of the azimuths of ripple and sole marks. This facilitates visual comparisons between cross-stratification and other primary bedding structures.

Tilt Correction

In cross-stratified rocks that have been subjected to post-depositional deformation, both the strike and dip of the true stratification and that of the cross-stratification have been changed. Before analysis of cross-stratification in such rocks can be made, they must be rotated to their pre-deformation attitudes. This was done by rotating the attitude of the cross-stratum, plotted on a Schmidt equal-area net, through the angle of dip of the regional stratum about the strike of the regional stratum. The writer assumed that the azimuth and the inclination of the cross-stratifica-

tion thus corrected are essentially the same as at the time of deposition. This method is explained by Bucher (1944), Badgley (1959, p. 187–214), and Phillips (1954).

Statistical Analyses

Circular histograms

A circular histogram is simply a normal, straight-line histogram plotted in a circular pattern from a single point. The normal abscissa corresponds to a circle divided into 30° classes; the normal ordinate corresponds to the radius of the circle divided into percentages. Circular histograms visually show general trends, modes, and the relative spreads of groupings of data. All readings of cross-stratification, ripple marks, and sole marks of each formation are represented by circular histograms when enough readings are available to warrant them.

Methods for determination of means, variance, and significance of data

Most geologists are familiar with the statistical methods used in sand grain analyses in which is employed the linear frequency curve to determine the mean, standard deviation, skewness, and kurtosis. This system requires an origin along a straight line. Because paleogeographic work deals with circular distributions, the problem is how to choose an origin for a circular distribution, that is, at what point of the compass 0° should be placed. Chayes (1954), Tanner (1955), and Curray (1956) have shown that the choice of the origin controls the resultant mean and variance and suggest using vectorial methods to avoid having to choose an origin in paleogeographic analyses.

Rather than employing graphic vector addition this writer chose to use trigonometric vector addition in terms of sine and cosine of each azimuth reading. The Tukey Orientation Test was used in which the 360° distribution of azimuth readings were divided into 30° intervals. Manipulation of the first part of the Tukey test estimates the resultant mean orientation ($\bar{X}_v$). The second part of the Tukey method tests the statistical significance of the resultant mean by use of the chi-square distribution. This indicates the probability of the estimated mean ($\bar{X}_v$) being the results of pure chance. For instance this writer found the resultant vector mean ($\bar{X}_v$) of cross-stratification in the Catskill rocks studied to be 311° with a significant level of 99.5th. (That is, 99.5 times out of 100 the resultant vector mean would be 311° using the azimuth measurements available.)

To measure the variance or spread of the azimuth readings the "Consistency Ratio" was used (Reiche, 1938). The results are stated in terms of 0% to 100%. If the azimuth readings (on the circular histogram) are in nearly all one direction the consistency ratio approaches 100%.

RESULTS

Primary Bedding Structures in the Devonian System

The Jennings Formation

Flint (personal communication) refers to the marine section of Upper Devonian rocks in Somerset County, Pennsylvania, as the Jennings Formation, the term applied to these rocks in Maryland. Other workers in south central Pennsylvania have called these strata the Chemung Formation. These two formations are probably the same, but the term Chemung should not be used now in south-central Pennsylvania, because the type locale of the Chemung Formation is several hundred miles to the north in New York State, and no exact correlation has yet been made between the Chemung Formation of New York State and the Upper Devonian marine rocks of south-central Pennsylvania.

The Jennings Formation is made up of interbedded sandstones, siltstones, shales, and some conglomerates. Primary bedding structures occur almost exclusively in the sandstones; a few are found in the siltstones and conglomerates. The top of the Jennings Formation interfingers with the non-marine Catskill Formation. The division between the two formations has been placed by Flint (report now in preparation) at the top of the highest bed containing marine fossils. The exact thickness of the Jennings Formation in this area has not been measured because at no place does the base of the Jennings crop out. An estimate of its thickness has been made by this writer with the use of a sample log from Well No. 3753, drilled by Peoples Natural Gas Company on the Harvey Marker farm at the crest of Negro Mountain anticline, about six miles northwest of Meyersdale. The thickness is estimated at about 1570 feet, from the base of the lowest red bed of the Catskill Formation to 50 feet below the lower conglomerate zone which crops out near the center of the Deer Park anticline.

A total of 37 outcrops were measured and sampled in the Jennings Formation. A rock sample from one set of cross-strata at each outcrop was described and classified according to Pettijohn's sandstone classification (1957, p. 290–91) with the aid of a binocular microscope. Of these 37 samples, there are 18 feldspathic sandstones, 10 orthoquartzites, 4 feldspathic graywackes, 3 arkoses, 2 protoquartzites, and 1 subgraywacke. These results suggest that the ultimate source of the Jennings is a plutonic rock body of deep-seated origin. The lack of detrital matrix and large percentage of quartz present suggest a mature sandstone deposited from a dilute fluid suspension. This interpretation substantiates the supposed interfingering relation between the deltaic Catskill deposit and the shallow marine and "slope" (Rich, 1950, p. 740) extension of this delta, where the Jennings was deposited. The Jennings contains marine fossils (brachiopods and crinoid stems).

Results of statistical analyses of bedding structures in the Jennings Formation can be seen in Figure 3. The vector mean of cross-stratification is 277°, inferring a source area to the east, and the significant value is at the 99.5 percentile. The consistency ratio is 18.9 percent. The histogram of cross-stratification displays a second minor mode toward the southeast. This is probably the result of error in measurement and error made during tilt correction using the Schmidt equal-area net. One flute cast points S.15°E., one group of current lineations trends N.55°W., and one group of eight rib-and-furrow structures show the current direction to be S.45°W. These three structures can not be considered very valid evidence of current direction because of their wide spread and sparse occurrence. Oscillation ripple marks, trending almost north and south, substantiate the mean of cross-stratification readings because they consistently trend nearly perpendicular to the inferred current flow.

These results agree very well with a primary bedding structure study made by Rich (1951). He found the paleocurrent flow to be westward in the Chemung Formation of southern New York and northern Pennsylvania.

The Catskill Formation

The Catskill Formation is composed of mostly red and maroon with some buff interbedded sandstones, siltstones, and shales containing widely scattered plant remains. A sample study log of Peoples Natural Gas Company Well No. 3753, was used to calculate the thickness of the Catskill Formation in southern Somerset County at about 2175 feet. The base of the Catskill, as stated previously, is placed at the top of the highest bed containing marine fossils, and the top of the Catskill is drawn "at the top of conspicuous red beds without regard to faunal subdivisions" (Flint, 1956).

Primary bedding structures in the sandstones and siltstones are abundant throughout the entire Catskill Formation. Outcrops of sandstone and siltstone are much more numerous in the Catskill Formation than in the Jennings Formation, due to the structural settings and the sand-shale ratios of the two formations. The Catskill Formation crops out along the scarp slopes of a breached anticline, whereas the Jennings Formation crops out along the center of the breached anticline. The sand-shale ratio of the Catskill Formation is 0.58; of the Jennings Formation, only about 0.07. These sand-shale ratios, calculated from the sample study log of Peoples Natural Gas Company Well No. 3753, show that the Catskill Formation has a much larger percentage of sandstone than the Jennings Formation.

In the Catskill Formation, 40 outcrops were measured and sampled. One rock sample was taken from one set of cross-strata at each outcrop,

RESULTS OF PRIMARY BEDDING STRUCTURE ANALYSES OF THE JENNINGS (CHEMUNG) FORMATION

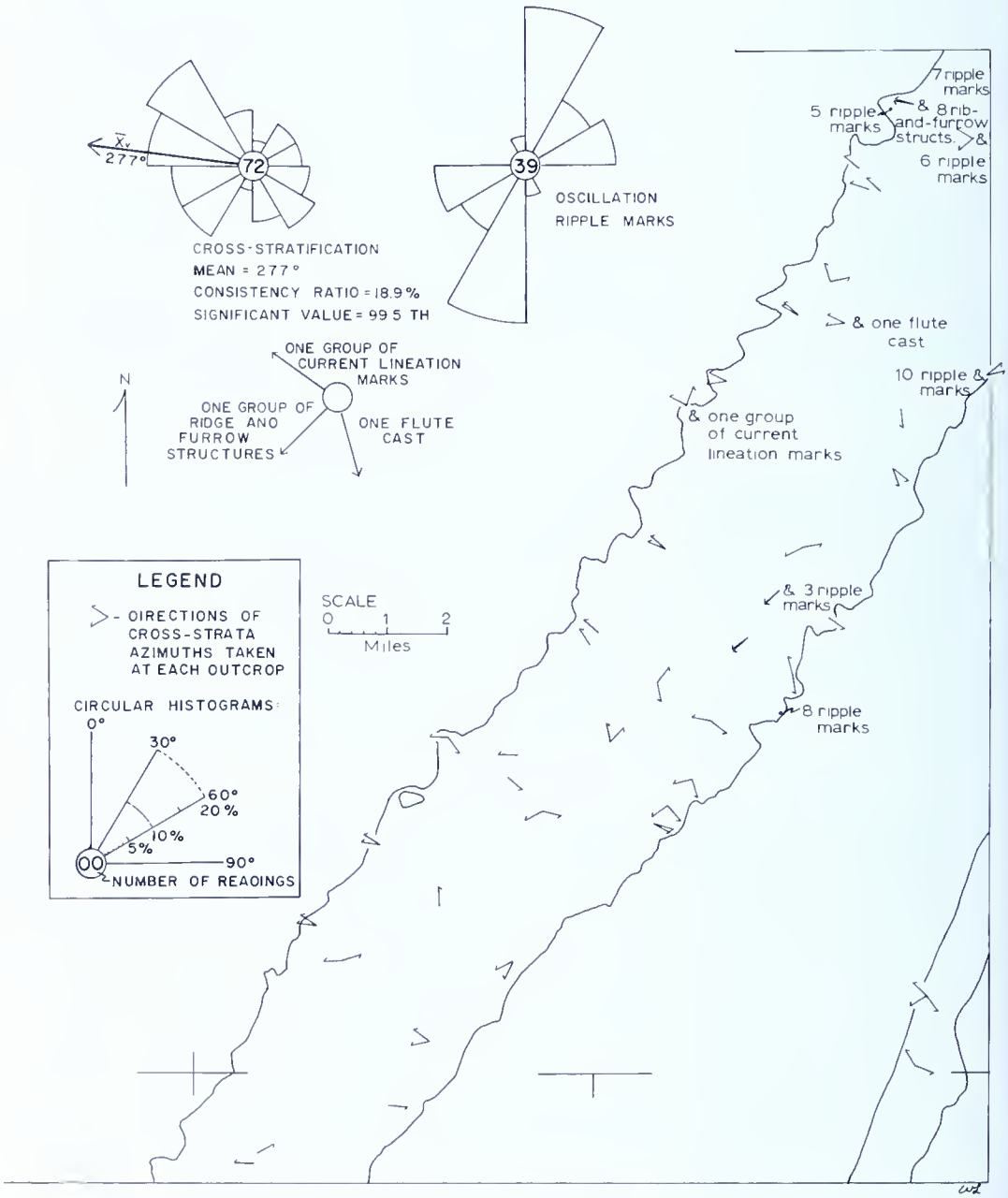

Figure 3.

and, in a few outcrops where a gross lithologic difference was apparent between the different sets of cross-strata, two samples were taken. These samples were analyzed with a binocular microscope. In summary, the results are: 24 feldspathic graywackes, 14 feldspathic sandstones, 2 lithic graywackes, 2 protoquartzites, and 1 arkose. The results indicate an ultimate source area (plutonic) similar to that of the Jennings Formation, as expected if the Jennings sediments are the offshore equivalent of those deposited on the Catskill delta. Sediments brought to and deposited on the delta were rich in feldspar and in-situ and disseminated clays altered from the feldspar, and were preserved mostly as such (Catskill type), but apparently sediments of the same source, which were carried farther offshore, were re-worked and the clay fraction winnowed out, leaving layers of relatively clean sandstones interbedded with thick sections of shale (Jennings type). The sand-shale ratios of the two formations favor this interpretation. The Jennings Formation (0.07) has a very low percentage of sandstones, and the Catskill Formation (0.58) has an almost two to one ratio of sandstones to shales. Most of the sand fraction of the oncoming sediments was deposited on the delta, and much of the finer sediments, clays and silts, were carried out to sea and deposited as the Jennings Formation.

Results of statistical analyses of primary bedding structures in the Catskill Formation are shown in Figure 4. The cross-stratification vector mean ($\overline{X}_v$) is 311°, inferring a source area to the southeast; the significant value is at the 99.5 percentile level. The consistency ratio is 30.5 percent.

The Catskill mean vector of 311° and the Jennings mean vector of 277° show that the paleocurrent flow directions shifted to the north as the Catskill delta deposition advanced westward over the Jennings sediments. This could mean a gradual southerly shift of the eastern source area occurred during Late Devonian deposition, or it could mean that the source area remained stationary, and offshore currents, re-working the Jennings sediments, caused a shift in the mean paleocurrent trends of cross-stratification.

Other primary bedding structures analyzed include 94 groove casts, 8 flute casts, 11 ripple marks, and 1 rill mark. From the histograms of these structures (Fig. 4), it can be seen that the groove casts, ripple marks, and rill mark substantiate the conclusions drawn from the cross-stratification analysis of the Catskill Formation. The flute-cast histogram approaches a random dispersion, and neither substantiates nor refutes the results gained from analyses of the other primary bedding structures.

The Jennings Formation displays abundant oscillation ripple marks and is virtually barren of groove and flute casts; the Catskill Formation has abundant flute and groove markings and few oscillation ripple marks. This relationship agrees with the delta-offshore correlation of the Catskill-

RESULTS OF PRIMARY BEDDING STRUCTURE ANALYSES OF THE CATSKILL FORMATION

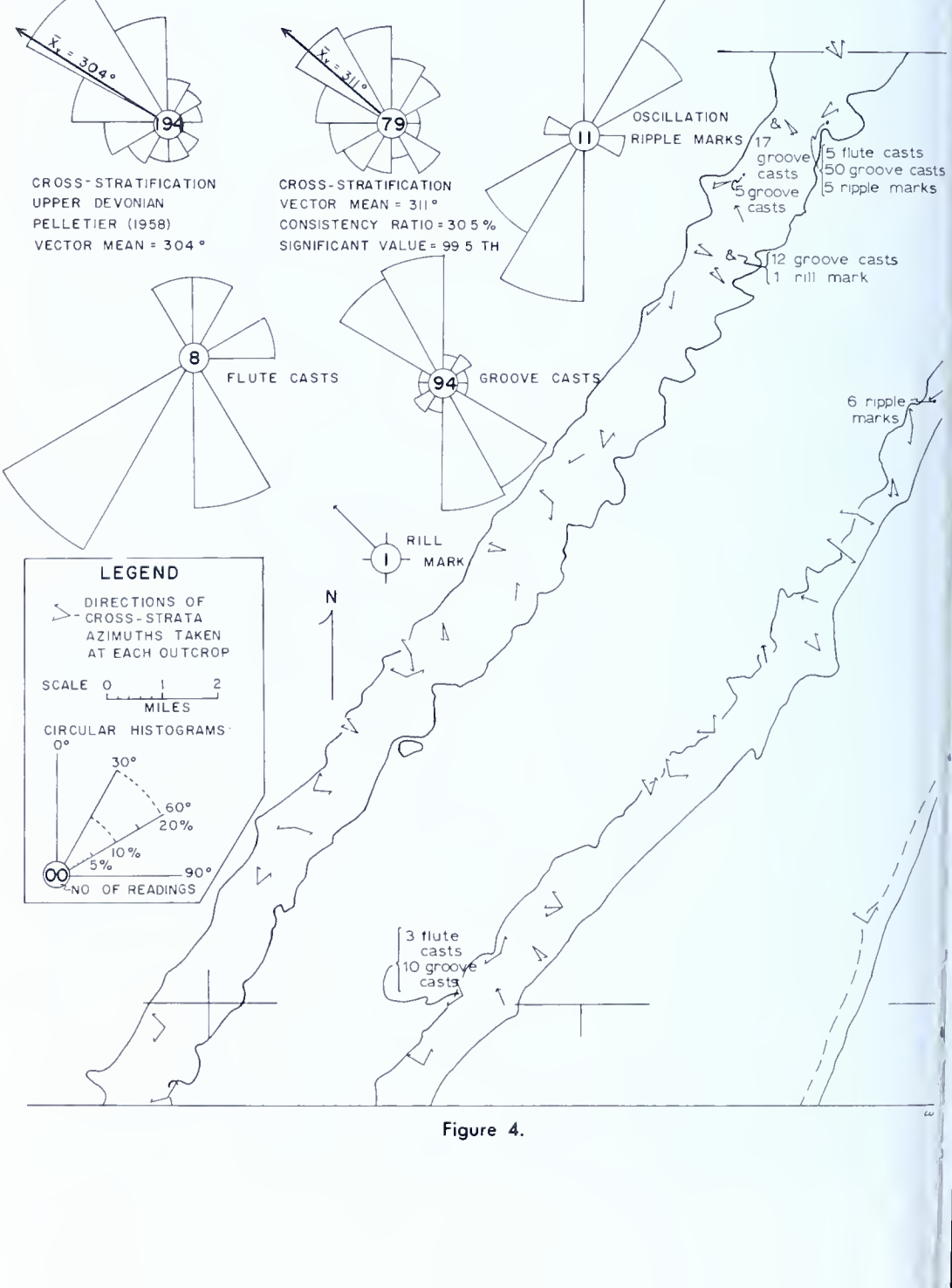

Figure 4.

Jennings depositional environments, because oscillation ripple marks are formed in relatively quiet water, whereas groove and flute marks are formed in more turbid water. The formation of groove casts is usually attributed to fast-moving laminar water flow that causes "tools" carried in suspension to scrape grooves in soft, fine bottom sediments. If this is true, the beds in the Catskill formation that contain abundant groove casts probably were deposited under flood conditions.

Upper Devonian composite results

The composite vector mean of cross-stratification for both the Catskill and Jennings Formation is 298°.

Included in Figure 4 are the results of Pelletier's study (1958, p. 1059) which included 194 cross-stratification readings taken at 13 localities of Upper Devonian outcrops in Pennsylvania and western Maryland. His mean of 304° for Upper Devonian rocks compares favorably with the Upper Devonian composite mean of 298° found in this study.

Sutton (1959) studied primary bedding structures in Upper Devonian rocks of the Finger Lakes region of New York. He found the resultant vector for flute casts was N.82°W. or 278°, and the consistency ratio 83 percent. A northwesterly to westerly direction was indicated by the averaged azimuths of 42 measurements of cross-strata.

That the results of studies by Pelletier (1958), Rich (1951), and Sutton (1959) which covered Upper Devonian rocks of western Maryland, Pennsylvania, and New York, agree so well with the results of this study, and with one another, suggests to the author that the source area of Upper Devonian rocks was not just a localized positive area east-southeast of Pennsylvania, but instead was a long, continuous source that roughly paralleled the present Atlantic coast of eastern United States.

Primary Bedding Structures in the Mississippian System

The Pocono Formation

The Pocono Formation is composed of mostly very fine- to medium-grained, thin- to medium-bedded gray and buff sandstones. Also present are minor amounts of shale and siltstones. The Burgoon Sandstone Member (Big Injun in drillers' terminology) lies at the top of the formation, and the Murrysville Sandstone Member lies 350 feet below. The total formation is 550 feet thick, and lies between the uppermost red beds of the Catskill Formation and the bottom of the Loyalhanna Limestone (Flint, 1956). The Pocono is exposed along Allegheny, Little Savage, and Little Allegheny Mountains. In the Pocono Formation, 16 outcrops were measured and sampled. Of the 16 sandstone samples classified, there were six feldspathic sandstones, three subgraywackes, three protoquartz-

RESULTS OF PRIMARY BEDDING STRUCTURE ANALYSES OF THE POCONO FORMATION

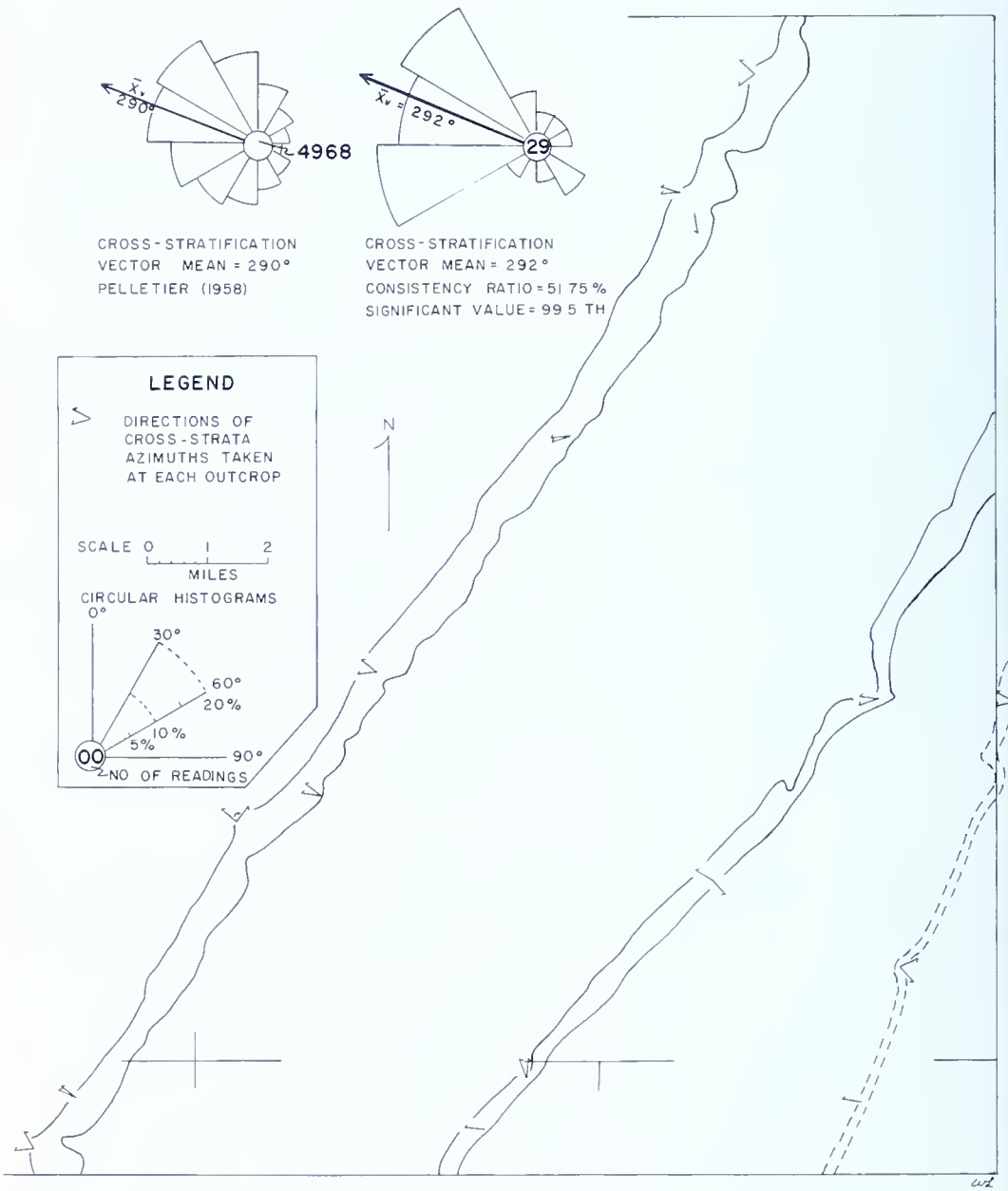

Figure 5.

ites, two feldspathic graywackes, one lithic graywacke, and one orthoquartzite. The large variety of sandstone types throughout the Pocono Formation makes it almost impossible to infer the general provenance and depositional environment with only 16 samples from this area. Pelletier (1958), after describing hundreds of samples in detail, suggested that the Pocono, a lithic arenite, is of fluvatile origin and was derived from clastic sediments and low-rank metamorphic rocks.

The only primary bedding structure found in the Pocono Formation was cross-stratification. Results of a study of this cross-stratification are presented in Figure 5. At the 16 outcrops visited, a total of 29 readings were taken. From the Tukey test the vector mean orientation is 292°, inferring a source area to the east-southeast, and the level of significance is at the 99.5 percentile level. The consistency ratio is 51.75 percent, showing little scatter and good grouping of azimuth directions.

Results of Pelletier's study (1958) are also presented in Figure 5 of this report. He found the Pocono mean paleocurrent direction to be 290°, only two degrees from the mean found by the writer.

SUMMARY AND CONCLUSIONS

A comparison of the cross-stratification vector means from this study (Jennings 277°, Catskill 311°, and Pocono 292°) shows the range of means to be only 34° (see Fig. 6). The shift in current directions during this long

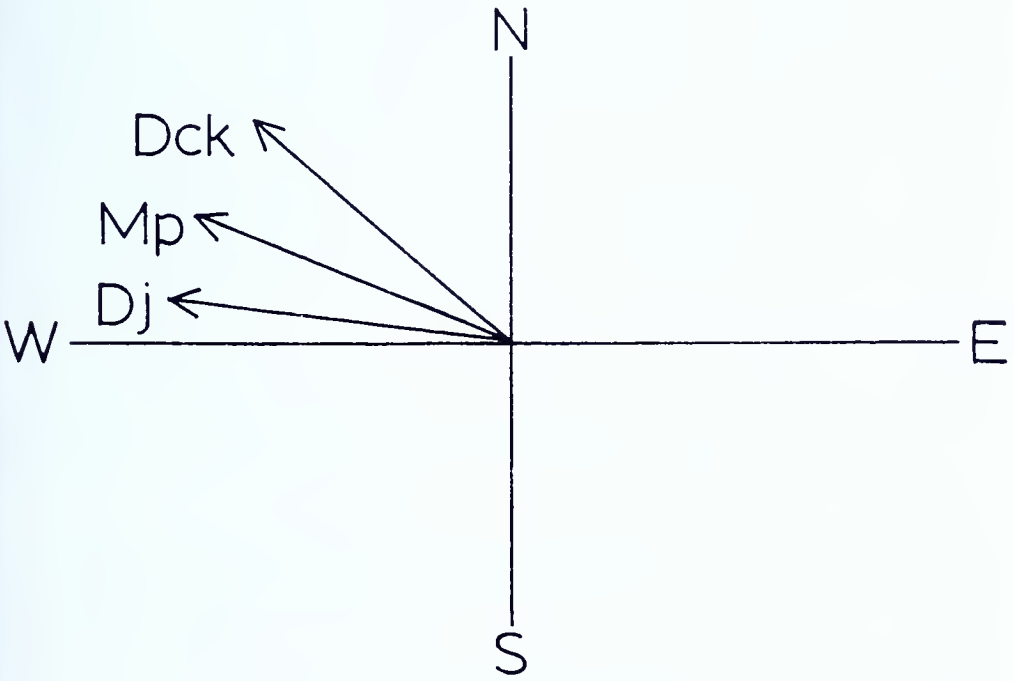

Figure 6.

period of geologic time was at best very small; the prevailing trend was west-northwest. A relative stability of tectonic conditions throughout this period of geologic time is also indicated.

This local study of primary bedding structures in southeastern Somerset County, Pennsylvania, has produced results which coincide with results of regional studies in the Appalachian Basin by Pelletier (1958). It is suggested that carefully made local paleocurrent studies in one formation can predict the regional paleocurrent trends of that formation. This procedure can be expected to work well in formations whose sandstones are widespread and of consistent lithology (e.g. all feldspathic sandstones or all orthoquartzites).

In formations whose sandstones vary greatly both vertically and laterally in lithology, this procedure probably will not be successful because no regional paleocurrent trends are present. During deposition of a formation with varying sandstone lithology, a variety of depositional environments were present within the depositional basin. This infers that a variety of current trends were also present, and no valid regional paleocurrent trend for that formation can be determined.

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Stratigraphy of the Nonred Upper Devonian Across Pennsylvania

ABSTRACT

The Chemung in Pennsylvania is determined to have no validity as a rock-stratigraphic unit; it is recommended that the term Chemung be restricted to use for a time-stratigraphic unit, the Chemung Stage of the Late Devonian. Use of the term Portage for a rock-stratigraphic unit is not possible without revising the meaning of the term, and, since Portage serves no critical need, abandonment of the name is suggested. The Parkhead Sandstone and Losh Run Members of the Fort Littleton Formation have little use as rock-stratigraphic units, and they are accordingly not included in the revised Fort Littleton. To encompass the strata previously designated Chemung, the Trimmers Rock Member of the Fort Littleton is expanded upward to the lowest Catskill red beds or the base of the Delaware River Flags.

In eastern Pennsylvania, the lower Trimmers Rock is a lithic equivalent of a portion of the Middle Devonian Mount Marion Formation of New York. A thick shale sequence, possibly representing the Mahantango, Burket, Brallier, and Harrell, splits the Trimmers Rock into two bodies, the lower of which is gradational downward into lower Mount Marion at Port Jervis.

The observed thicknesses of the Brallier and Trimmers Rock Members of the Fort Littleton Formation suggest that at the time of deposition an area of relatively rapid accumulation trended east-northeast through central Pennsylvania, bounded on the south by an area of relatively slight accumulation.

INTRODUCTION

The nonred rocks of the Upper Devonian section in the Appalachian region consist of all strata above the base of the Late Devonian (?) Tully Limestone or its age equivalents and below the Catskill Formation or the Delaware River Flags. In Pennsylvania these strata approach four thousand feet in maximum thickness and have been split into the Portage Group below and the Chemung Group above. The boundary between Portage and Chemung is drawn at the lowest occurrence of *Spirifer disjunctus* (Willard, 1935b, p. 1195).

A primary purpose of this paper is to evaluate the terms Portage Group and Chemung Group or Formation using as a guide the Code of Stratigraphic Nomenclature of the American Commission on Stratigraphic Nomenclature (1961). Revisions in the terminology of the Fort Littleton Formation are also made in accordance with the Code.

In an attempt to determine the regional distribution of the members of the Fort Littleton Formation, nineteen stratigraphic sections from Port

Jervis, New York to Oldtown, Maryland were examined in detail, and the results are given here in a general way. Lithic counterparts of the members of the Fort Littleton in New York, Maryland, and West Virginia are noted, and the nomenclature used in those states is compared with the terminology used in Pennsylvania.

DISTRIBUTION

The nonred Upper Devonian rocks are well exposed in the Pennsylvania salient of the Valley and Ridge Province and extend in unbroken bands both northward into New York and southward into Maryland, West Virginia, and Virginia. The western margin of the outcrop belt occurs along the Allegheny Front, which is gently arcuate in Pennsylvania and somewhat more irregular in West Virginia. For the most part the easternmost occurrences lie shortly west or northwest of Blue Mountain, the western boundary of the Great Valley. Nonred Upper Devonian rocks are also extensively developed along the Pennsylvania-New York border, northeast of the well-marked Appalachian Front. The widespread subsurface occurrences of western Pennsylvania will not be discussed in this paper.

Many prominent problems in the stratigraphy of the nonred Upper Devonian rocks of Pennsylvania relate to the distribution of surface occurrences. Most importantly, the outcrop belt is continuous from southern Pennsylvania northward along the Allegheny Front to Luzerne County but not directly into the type sections in central New York. Rather, a circuitous route must be followed through the Valley and Ridge Province and along the margin of the Great Valley to the eastern New York exposures. Consequently, it is not possible to trace units in southern Pennsylvania, as well as Maryland and West Virginia, into the classic areas in central New York because of multiple changes in lithology and fauna.

NOMENCLATURE

General

The generalized stratigraphic section for the nonred Upper Devonian of Pennsylvania may be discussed without detailed reference to the involved history of its development. Notable advances have been made by such workers as I. C. White, Charles Butts, and Bradford Willard, and without their excellent work as a foundation, present work would be mere reconnaissance. But the science of stratigraphy is not static; changes in the principles and methodology have been abundant during its development. Thus, the Upper Devonian has been studied from several viewpoints, and many times it has served as the area of discovery or the proving ground of a new method. A present revision of nomenclature is made

necessary by changes in stratigraphic procedures embodied in the Code of Stratigraphic Nomenclature (1961).

Biostratigraphic Units and Time-Stratigraphic Units

The principles of biostratigraphic correlation were first developed in an effort to establish contemporaneity or relative age of separated rock bodies. The environmental significance of faunas was recognized somewhat later. Since answers provided by these methods can many times be obtained in no other way, the value of biostratigraphic units cannot be overemphasized. Modern practice, however, makes two prime distinctions not observed in the pioneer work: biostratigraphic units are distinct 1) from time-stratigraphic units and 2) from rock-stratigraphic units.

The utility of Upper Devonian biostratigraphic units under both the previous and the present systems is exemplified by the "Chemung." Although in the original designation of the "Chemung" (Hall, 1839, p. 322–326) both faunal and physical bases for recognition were described, it was found in subsequent work that lithologic and faunal criteria diverged. Because the faunal differences are more obvious, the "Chemung" in Pennsylvania was defined by Willard (1935b, p. 1195) on the basis of the occurrence of the "Chemung" fauna. Cooper and others (1942) further applied the term as a stage name for the Upper Devonian. Hence, the term "Chemung," often used with the terms "formation" and "group," came to have two separate meanings: 1) a group of rocks containing a certain fauna, and 2) a span of time representing accumulation of the rocks. Such dual usage is represented in this discussion by the use of quotation marks.

Modern terminology requires that Formation or Group be used only in designating lithic units. A section of rocks distinguished in the field by its fauna cannot be termed a formation, but rather falls into the category of the biostratigraphic unit (Code of Stratigraphic Nomenclature, 1961, Article 19). Accordingly, the "Chemung" seems most properly to be an assemblage zone (Code of Stratigraphic Nomenclature, 1961, Article 21), but locally at least it represents the range of *Spirifer disjunctus,* in which case the "Chemung" is a range zone (Code of Stratigraphic Nomenclature, 1961, Article 22). In either case, the fauna deserves detailed work and new designations in keeping with the Code of Stratigraphic Nomenclature (1961, Article 24).

Chemung has been applied in a time-stratigraphic sense in the Devonian Correlation Chart (Cooper and others, 1942) as a stage of the Upper Devonian. Because in this sense Chemung is an accepted term, and because its use as a rock-stratigraphic term has no justification, it is recommended that Chemung be restricted to use as a stage name.

The Upper Devonian rocks beneath the Catskill in Pennsylvania were

generally divided by the early workers into "Chemung" above and Portage below. The common boundary was drawn at the position of the lowest "Chemung" fauna. Therefore definition of the Portage likewise rests on faunal criteria, even though its base is usually marked by lithologic changes. In effect, the Portage in Pennsylvania represents the assemblage zone of the Naples and Ithaca faunas. It is doubtful whether Portage has any useful application, except with the proper modifications to make it a rock-stratigraphic term for use as a Group. Use of Portage Group is not recommended, however, because in the absence of the Tully Limestone lithologic change is not always apparent at the base.

Other less extensively developed units have found some use as biostratigraphic units in Pennsylvania. The Parkhead Sandstone Member of the Jennings Formation of Maryland was originally distinguished both lithologically and faunally (Stose and Swartz, 1912, p. 12). Willard (1935b, p. 1199-1200) referred the unit to the Fort Littleton Formation in Pennsylvania as the Parkhead Sandstone Member, but his criteria for recognition were strictly faunal. It seems likely that the fauna of the Parkhead may constitute a valuable assemblage zone, but the term Parkhead Sandstone Member has little use in Pennsylvania because the unit cannot be distinguished lithically.

The Losh Run Member of the Fort Littleton Formation (Willard, 1935b, p. 1206) also has doubtful value as a rock-stratigraphic unit, although the *Reticularia laevis* zone which it contains may prove with further study to be of use as a biostratigraphic unit.

Rock-Stratigraphic Units

It has already been pointed out that such terms as Portage, "Chemung", Parkhead Sandstone, and Losh Run do not conform to modern requirements for rock-stratigraphic units and therefore should not be used in conjunction with the terms Group, Formation, and Member. The historical usage of Portage and "Chemung" has been such that they applied to all rocks between the Tully Limestone and the highest *Spirifer disjunctus;* removal of these terms from usage means that certain portions of the section are left unnamed and certain other portions are left without Group designation. Both conditions may be remedied rather simply.

The rocks called Portage Group were divided by Willard (1935b, pp. 1198–1199) into two formations, the Rush below and the Fort Littleton above. No essential need is served by combining these two formations into one unit of Group status; each unit stands independently.

The line of division between the Portage and the "Chemung" is drawn at the lowest occurrence of *Spirifer disjunctus,* in a continuous section of lithologically identical strata. The top boundary of the "Chemung" is drawn on the highest occurrence of the same brachiopod. In many cases

this is hundreds of feet above the lowest red shale, which is properly the base of the Catskill Formation. The disposition of the rocks lying below the lowest Catskill red shale and previously assigned to the "Chemung" is conveniently settled by designating them a part of the rock-stratigraphic unit which they resemble and which they directly overlie. By this procedure the Fort Littleton Formation is expanded to include a considerable thickness at its top. In all sections examined the added strata are lithologic counterparts of the Trimmers Rock Member of the Fort Littleton.

The Fort Littleton Formation is thus redefined as all strata having the lithologic characteristics of its members; these are in ascending order the Harrell Member, the Brallier Member, and the Trimmers Rock Member. With exceptions noted later, the basal boundary of the Fort Littleton Formation is placed at the highest occurrence of the Burket Member of the Rush Formation, and the top contact at the lowest occurrence of red shale of the Catskill Formation. Mappability of the basal contact is demonstrated on many published maps (For example, Miller, 1961, Conlin and Hoskins, 1962). The contact with overlying red shales having color designations in the range 5 R 4/2 to 10 R 4/2, (Goddard and others, 1951) has proved mappable in central Pennsylvania but the reports are as yet unpublished.

Willard (1935a, p. 123) first designated the Trimmers Rock Sandstone but soon after termed the same rocks the Trimmers Rock Member of the Fort Littleton Formation (1935b, p. 1200). Because the Trimmers Rock is most frequently referred to as a member of the Fort Littleton Formation, continuation of that usage is recommended. The Trimmers Rock Member of the Fort Littleton Formation is redefined here as that body of dominantly gray sandstones, siltstones, and shales lithologically similar to and physically continuous with the strata at Trimmers Rock on the Juniata River, the type section. In a report now in preparation, the writer will present a number of reference sections for the purpose of supplementing the type section, which is faulted, incomplete, and not described in detail.

LITHOSTRATIGRAPHY

General Statement

The remainder of this paper will be devoted to discussion of the lithostratigraphy, or spatial relations of the rock-stratigraphic units, of the nonred Upper Devonian of Pennsylvania, paying particular attention to the Trimmers Rock Member of the Fort Littleton Formation.

In the field study on which this paper is based, efforts were made to record the obvious lithologic characteristics of the nonred Upper Devonian strata. The work consisted of observation and description of such fea-

tures as rock-type, color, bed thickness, and primary structures. Gross rock-type is probably the most valid tool for fundamental lithic correlation and for field-mapping because variability of rock-type seems to be less than that of other features. The distribution of most lithostratigraphic units is therefore established by the three-dimensional extent of the gross rock-type which typifies the unit.

The nonred Upper Devonian of Pennsylvania consists of the formal units listed in the following table:

Fort Littleton Formation
- Trimmers Rock Member
- Brallier Member
- Harrell Shale Member

Rush Formation
- Burket Shale Member
- Tully Limestone Member

Tully Limestone Member of the Rush Formation

The Tully Limestone has frequently been accepted as the earliest Late Devonian unit in the Appalachian region, and for the purposes of this discussion will be considered as Late Devonian in age, although convincing arguments have been advanced for assigning the Tully to the Middle Devonian.

Distribution of the Tully Limestone in Pennsylvania is perhaps best seen in the results of the study by Jones and Cate (1957, Plate 6). This map shows that in east-central Pennsylvania, sandstone and calcareous shale replace limestone of the Tully, but whether these sandstones and shales represent a traceable continuation of the Tully Limestone is unknown. The Tully Limestone is unusually well developed in Sullivan, Lycoming, and Clinton Counties, where the unit consists of more than 200 feet of fossiliferous light-gray limestone lithologically similar to the Onondaga Limestone. A series of thin limestones and calcareous shales occurs in the approximate position of the Tully in western New York and Pennsylvania. The highest of these layers is generally termed Tully Limestone. On a regional scale the Tully seems to be confined to New York and Pennsylvania as no occurrences have been noted in Maryland, West Virginia, or Virginia (Woodward, 1943, p. 387).

A significant aspect of Tully distribution is its absence in the region of the Broad Top Basin (see Jones and Cate, 1957, plate 6).

Evaluation of the Tully Limestone as a lithostratigraphic unit must necessarily be conservative because the facts concerning its distribution are meagre. The recommendation is made, however, that the terms Tully Limestone or Tully Member of the Rush Formation be applied only to limestones which lie immediately below the Burket Member of the Rush

Formation. Designation of thin calcareous shales or sandstones containing *Hypothyridina venustula* as Tully is not warranted because of the marked difference in rock type. Without question the zone of *Hypothyridina venustula* is a significant biostratigraphic unit in Pennsylvania and deserves to be delimited. Perhaps by study of this zone it will be possible to critically evaluate the sequence of thin limestones in the western part of the state.

Burket Shale Member of the Rush Formation

The Burket Shale was originally designated as a member at the base of the Harrell Shale (Butts, 1918, p. 523) and subsequently made a member of the Rush Formation by Willard (1935b, p. 1209). Lithologically the Burket is quite distinctive, consisting of highly fissile black shale which frequently weathers to a medium-bluish-gray color.

Distribution of the Burket Shale Member of the Rush Formation is irregular, and thickness is determined with difficulty because of the extremely tight folding which affects the Burket in almost every section. Generally, however, the Burket is about 80 feet thick in the region of the Allegheny Front where it was first named. Black shales below the Brallier Member of the Fort Littleton are well developed in the Broad Top Basin, alternating with gray shales through a thickness in excess of 200 feet at Saxton in Bedford County. These black shales thin and apparently disappear to the south. Because the black shales of the Broad Top region cannot be traced at the surface into the Burket of the Appalachian Front, it is not certain that the two bodies are the same. Moreover, lithic differences noted by Butts (1918, p. 524; 1945, p. 10) indicate a significantly different section in the Broad Top region.

The term Burket Shale has not been utilized in Maryland and West Virginia. Upper Devonian black shales do occur in both states, however, and have been termed Genesee Black Shale Member of the Jennings Formation in Maryland (Schwartz, 1913, p. 411) and Harrell Shale in West Virginia (Woodward, 1943, p. 390). In West Virginia, the Harrell Shale is used to include both black shale and interbedded black and gray shales below the Brallier. This usage is in agreement with Butts' original usage, in which the interbedded black and gray shales were termed Harrell, but not in accord with Butts' designation of homogeneous black shales as Burket.

Because of its common position in a topographic low, the Burket is traced with difficulty but seems to be present in separated sections throughout the Susquehanna Valley south of Sunbury. Reconnaissance by the writer disclosed black shale beneath the Brallier and Trimmers Rock Members of the Fort Littleton Formation in Montour, Columbia, and Lycoming Counties. It is therefore likely that black shales are continuous at the surface from the type locality of the Burket in Blair County

north along the Allegheny Front and thence into the Susquehanna region. Relationships of the Burket to the central New York units cannot be ascertained from surface study because the outcrops are not continuous. Northeastward from the Susquehanna along Blue Mountain, black shale is present below the Trimmers Rock in several sections, the most easterly of which is Bowmanstown, Carbon County. Dark-gray shales are very common in sections still farther northeast, but the Burket could not be distinguished.

Harrell Shale Member of the Fort Littleton Formation

The Harrell Shale (Butts, 1918, p. 524) was designated a member of the Fort Littleton Formation by Willard (1935b, p. 1207–08). As already noted, its basal unit, the Burket, was named a member of the underlying Rush Formation. The Harrell Shale Member of the Fort Littleton Formation consists of "dove-colored" or medium-to dark-gray shales lying above the Burket and below the Brallier or Trimmers Rock Members of the Fort Littleton Formation (Willard, 1939, p. 217).

In regard to color, which is the basis for separating the Harrell from the Burket, it should be noted that local weathering plays a significant part in determining the color ultimately seen in outcrop. Moreover, it is frequently difficult to distinguish black from very-dark-gray colors in the field. Under ideal conditions the boundary between the Burket and Harrell is sharp and unequivocal; Butts (1945, p. 10), however, has pointed out that in the Broad Top region black shales occur intermittently through at least the lower 145 feet of the section. In such cases Butts expanded the Harrell to include the interbedded black shales and did not recognize the Burket. Further work may show the need for a new term to apply to these interbedded black and gray shales, in order to differentiate them from the Burket-Harrell sequence.

In all sections examined by the writer, the gray shales of the Harrell underlie either blocky siltstones and shales of the Brallier or sandstones and shales of the Trimmers Rock. The position of the Harrell in eastern Pennsylvania is established with difficulty, however. In the Hess well, about 8 miles north-west of Port Jervis, New York, a thick shaly section occurs in the expected interval and may be Harrell. Low topography and poor exposures occur in the same stratigraphic position of nearby surface sections so that surface description of lithology are not available. It is considered likely that this 700 foot interval is the eastward continuation of the Harrell together with a portion of the shaly Mahantango strata. If this interpretation is correct, the Harrell Shale is situated between the main body of the Trimmers Rock above and a tongue of Trimmers Rock below.

Thickness of the Harrell Shale Member of the Fort Littleton Formation can be obtained only rarely because the unit is often partially or

completely covered. As a consequence only general statements can be made. The Harrell is slightly more than 200 feet thick along the Allegheny Front. In the Susquehanna Valley the Harrell thins irregularly southward from about 240 feet at Sunbury to approximately 190 feet at Marysville. The sections exposed north of Blue Mountain eastwardly into Pike and Monroe Counties display a shaly interval several hundred feet thick, but outcrops are discontinuous and structurally separated so that accurate thicknesses cannot be determined.

Interbedded gray and black shales of the Broad Top Basin are overlain in sharp contact by the Trimmers Rock Member of the Fort Littleton Formation. Future study of the Upper Devonian in this structure may disclose whether the gray and black shales are continuous into Maryland and West Virginia, and if so, what their relationships are to the Burket both east and west of the Broad Top structure.

Brallier Member of the Fort Littleton Formation

Above the shaly sequence just described lies a section of distinctive siltstones and sandstones. These rocks are exceptionally well-exposed in highway and railroad cuts immediately east of Huntingdon in the Broad Top Basin. Butts (1918, p. 523) designated this unit the Brallier Shale and successfully mapped it through the Huntingdon and Hollidaysburg Quadrangles (1945). Willard (1935b, p. 1207) subsequently renamed the unit Brallier Member of the Fort Littleton Formation, although he frequently referred to the strata as "Brallier shale." Because the Brallier consists predominantly of siltstone rather than shale, the term Brallier Shale is considered to be not representative of the lithology and should be abandoned.

The Brallier Member of the Fort Littleton Formation consists of light- to dark-gray siltstones with common interbedded sandstones and shales. The most distinctive characteristic of the siltstones is the remarkably planar aspect of the bedding surfaces. Irregularity of bedding planes is rare, and thickness of individual beds varies only slightly for hundreds of feet in the Huntingdon section. Secondly, the Brallier is distinguished by a tendency to weather to thin flakes; this characteristic imparts a pseudofissility to the siltstones, which therefore superficially resemble shale.

Regionally, rocks termed Brallier have an extensive development in states south of Pennsylvania but cannot be traced at the surface into New York. Butts, however, has pointed out the lithologic similarity of the Brallier to the Hatch and Gardeau Shales of central New York (1940, p. 320). In Maryland rocks of Brallier lithology constitute only a portion of the Woodmont Shale Member of the Jennings Formation, the remainder probably being Harrell. In West Virginia the great bulk of shaly strata called Brallier by Woodward (1943, p. 412) consist of gray to

olive-green shales and thin interbedded sandstones. These rocks are closely similar to the Trimmers Rock and do not resemble the Brallier lithologically.

In Pennsylvania the Brallier is well developed west of the Susquehanna River. Butts (1945) mapped Brallier along the Allegheny Front and also in the northern Broad Top Basin. Because the Brallier is commonly poorly exposed, thickness figures are obtained with difficulty, but the Brallier appears to be somewhat thicker along the Front than at Huntingdon. In this regard, Butts' figures cannot be utilized because his practice was to extend the Brallier up to the lowest "Chemung" fauna (1945, p. 11). East of Huntingdon the present writer measured 494 feet of strata having Brallier lithology; possibly 200 feet more at the base is covered. In contrast, Brallier siltstones dipping uniformly westward crop out intermittently throughout at least 1000 feet of section along the Pennsylvania Railroad right-of-way west of Altoona. Complete sections of the Brallier at the Front are unknown at present, in spite of a systematic search along its length.

Variation in thickness is also notable within the Broad Top Basin. At Saxton, twenty-two miles southwest along the strike from Huntingdon, the Brallier is not recognized. It is possible that the Brallier is not present at Saxton and that the Harrell directly underlies the Trimmers Rock, but exposures in the critical area are equivocal. If the Brallier Member is present at Saxton it is necessarily thin because the interval from the base of the Trimmers Rock to recognizable Mahantango shales is only slightly more than 200 feet. This thinning does not appear to be the result of faulting because all upper Devonian units thin stratigraphically in the latitude of Saxton. Still farther southwest along the strike at Oldtown, Maryland, typical Brallier siltstones occur sporatically through the basal 210 feet of the Trimmers Rock. This relationship suggests that the Brallier is replaced by the Trimmers Rock toward the south. A structurally complex section near Warfordsburg in Fulton County reveals only 22 feet of definite Brallier, suggesting that a similar relationship exists to the southwest as well.

It seems certain that the Brallier cannot be traced from the Allegheny Front into the northern portion of the Susquehanna Valley. At Lock Haven, Sunbury, and Catawissa the Trimmers Rock lies directly on gray shales of Harrell lithology, and Brallier siltstones are intermittently present throughout almost 2000 feet of Trimmers Rock. In this region, then, the Brallier and Trimmers Rock are intricately interbedded and non-separable.

In the Susquehanna Valley southward from about the latitude of Port Trevorton, Juniata County, the Brallier is recognizable as a discrete unit below the Trimmers Rock and above the Harrell. Sections along Routes

11 and 15 north of Liverpool and at Girty's Notch display excellent exposures of the Brallier, which here attains a thickness of 430-450 feet. At Dromgold and Marysville in Perry County, the Brallier is not present. The Brallier Member of the Fort Littleton Formation is thus excellently developed between Port Trevorton and the mid-latitude of Perry County, goes out suddenly toward the south, and occurs as interbeds through most of the Trimmers Rock Member to the north.

East of the Susquehanna Valley, rocks of Brallier lithology occur at New Ringgold, Schuylkill County, and north of Bowmanstown, Carbon County. Approximately 135 feet are present at New Ringgold and 160 feet at Bowmanstown, but the two bodies do not appear to be continuous. The most easterly known Brallier is exposed north of Stroudsburg, Monroe County, along Brodhead Creek. The unit undoubtedly extends farther to the east because the Brallier measures 212 feet at this locality; more work is needed to solve this problem.

The value of the Brallier as a member of the Fort Littleton Formation cannot be denied. In general, mappability of the Brallier is poor, particularly where it is poorly developed, but the unit fulfills the basic requirements of a member (Code of Stratigraphic Nomenclature, 1961, Art. 7a–7b). In the regions where it is best developed the Brallier constitutes a rock-body of distinctive characteristics and is easily separated from the Harrell and Trimmers Rock Members. Like most rock-stratigraphic units, however, the Brallier is not everywhere clearly delineated, and eventually it may prove necessary to utilize arbitrary cut-offs (Code of Stratigraphic Nomenclature, 1951, Art. 5e) in order to separate a unit of mixed lithology from both the Brallier and the Trimmers Rock.

Trimmers Rock Member of the Fort Littleton Formation

As already discussed, the Trimmers Rock Member of the Fort Littleton is expanded here to include all rocks of Trimmers Rock lithology lying below distinctive red shales. The added rocks consist of that portion of the range zone of *Spirifer disjunctus* beneath the red shales and heretofore termed "Chemung".

Although the Trimmers Rock appears to be a monotonous sequence, detailed studies show that several lithic features are quite variable. Only by recording all discernible physical properties at a number of localities was it possible to determine the least variable characteristics which unify and define the Member. The highly variable properties, although they do not strictly define the unit, are of value, however, because they frequently provide information about genesis, paleogeography, provenance and post-depositional processes. The defining features of the Trimmers Rock are the major rock-types which it contains and the planar nature of the beds. Grain size is not considered definitive because of great

variation within single beds and locally through the section. Post-depositional changes in the rocks are so variable and their effect on color so marked that only general statements can be made about this property. Moreover, there appears to be considerable color-variation which is not the result of secondary processes. Physical features of such irregular distribution that they cannot be considered definitive include bed thickness and degree of development of fissility. Attributes such as fossil-fragment layers and sedimentary structures of mechanical origin are too commonly absent to be significant. Primary structures of organic origin, on the other hand, are ubiquitous and perhaps diagnostic.

Lithologically, the Trimmers Rock Member consists of shale, siltstones, and sandstone. Shale constitutes more than half of all measured sections, and shale intervals range in thickness from mere partings to several tens of feet. The more prominent and persistent shale bodies may be utilized in comparing separated sections of the Trimmers Rock. Siltstones and sandstones of the Trimmers Rock are dominantly graywackes and subgraywackes (Pettijohn, 1957, p. 291); their petrology has been discussed elsewhere (Frakes, 1962, p. 208). Subgraywackes appear to be most common near the top of the section. Conglomeratic sandstones are limited in occurrence to the upper half of the unit and are not abundant. Conglomeratic sandstones in this part of the section are in many cases too lenticular to be considered as throughgoing units.

The Trimmers Rock Member of the Fort Littleton Formation overlies the Brallier Member in those regions where the Brallier is developed and can be separated. Between Port Trevorton and Dromgold in the Susquehanna Valley, the contact is abrupt and easily recognized. The same clear relationships prevail at New Ringgold and Bowmanstown in eastern Pennsylvania and at Huntingdon in the Broad Top region.

As previously discussed, the Brallier north of Port Trevorton apparently interfingers with the Trimmers Rock; the distinctive Brallier siltstones occur intermittently well up into the Trimmers Rock. In these sections the dominant Trimmers Rock lithology overlies gray shales of the Harrell, usually in a gradational relationship. The same situation prevails in most of south-central Pennsylvania, but the contact is very sharp at Saxton.

The relationship of the Trimmers Rock to units beneath it is very complex in Pike and Monroe Counties in eastern Pennsylvania. Additionally, the shaly units of the Upper Devonian are seldom seen in the exposed sections, and the glacial cover hinders mapping. In spite of these conditions some indication of the distribution of the Trimmers Rock may be gained from study of the few long sections, a few dry holes, and many isolated outcrops. The Brallier is present beneath the Trimmers Rock from Bowmanstown eastward at least as far as Stroudsburg although it is con-

sidered likely that this eastern body is lower in the section and not continuous with the Brallier of the Susquehanna Valley. East of Stroudsburg, rocks of Trimmers Rock lithology are transitional downward into medium- and dark-gray homogeneous siltstones which show bedding planes only rarely. These distinctive strata closely resemble and are along strike from the lower portion of the Mount Marion Formation of Middle Devonian age (Grabau, 1917, p. 954; Chadwick, 1944, p. 107; Fink and Schuberth, 1962, map of Otisville quadrangle).

The above relationships are best seen in the cuts along Routes 42 and 97 on the northern outskirts of Port Jervis, New York, where about 275 feet of lower Mount Marion strata lie in sharp contact on the sooty-black Marcellus Shale. The Mount Marion and Trimmers Rock lithologies are interbedded through the succeeding 56 feet, and the Trimmers Rock is exposed above a covered interval of about 242 stratigraphic feet. In this section as in most of eastern Pennsylvania, the position of the Harrell and Brallier Members is unknown. Two possibilities exist: 1) both units wedge out or interfinger with adjoining rocks east of Stroudsburg or 2) both units are present but not seen in the region of Port Jervis. The presence of a distinct 700 foot shaly interval in the Hess well eight miles to the northwest and a covered interval of about the same thickness at Port Jervis indicates that the Harrell and possibly the Brallier, together with a shaley portion of the Mahantango Formation, are present in this region. Significantly, however, these units if present, lie at least 600 feet *above* the lowest occurrence of the Trimmers Rock.

If the above interpretations are correct, a thick lower tongue of Trimmers Rock exists eastward of Port Jervis, probably extending and terminating westward in Pennsylvania.

Relationships between the Trimmers Rock Member of the Fort Littleton Formation and younger rock-stratigraphic units are generally simple in that the Catskill overlies the Trimmers Rock throughout the state, except in Pike and Monroe Counties. At present, however, it is not possible to state the exact nature of the Catskill-Trimmers Rock relationship. The most significant facts bearing on this problem are generalized as follows: 1) the base of the Catskill occurs at progressively lower levels toward the east; 2) the base of the Catskill also occurs at progressively lower levels toward the *south;* 3) the base of the Catskill occurs somewhat higher in the section on two major anticlines than it does in the adjacent synclines. The variable position of the lowest red shales contributes significantly to variation in the thickness of strata designated as Trimmers Rock.

The lowest beds of the Catskill Formation, commonly red shales, overlie the Trimmers Rock in sharp contact. Locally, rusty-brown beds within the upper Trimmers Rock cause some confusion, but careful use of the Color Chart distinguishes the true red colors. Above the lowest red,

most sandstones and many shales are lithic counterparts of Trimmers Rock beds.

At Stroudsburg and sections and wells farther east, the Trimmers Rock is overlain conformably by the Delaware River Flags, also of Late Devonian age. At Stroudsburg and Winona Falls the distinctive green Delaware River Flags are interbedded with typical Trimmers Rock sandstones and shales through a thickness of at least 144 feet. This transitional relationship is also seen in the Haag well, Pike County. At Port Jervis and in the Hess well, however, the Delaware River Flags lie in sharp contact on the Trimmers Rock.

In those areas where the Delaware River Flags lie above the Trimmers Rock, the lowest red shales of the Catskill are found in a considerably higher position. In effect, the Delaware River Flags occupy an interval between the Trimmers Rock and the Catskill Formation, and where the flagstones are not present, the Catskill lies directly on the Trimmers Rock. The question arises whether the Delaware River Flags replace the Trimmers Rock or the Catskill or both. The existence of a Trimmers Rock-Delaware River transition zone and the fact that the base of the Delaware River Flags is stratigraphically lower at Port Jervis than at Stroudsburg suggest strongly that the Delaware River Flags are largely lateral equivalents of the upper Trimmers Rock. Quite possibly the Delaware River Flags are related in a similar manner to the lower Catskill.

The thickness of Trimmers Rock strata included between the contacts described above varies from well over 3000 feet along the Allegheny Front and at Oldtown, Maryland to only 450 feet at Saxton. At Port Jervis the section from the top of the Trimmers Rock-Mount Marion transition zone to the base of the Delaware River Flags measures about 1950 feet, but it must be noted that this figure includes the 700-foot covered interval which probably should not be considered Trimmers Rock. Additional measurements show a relative constancy of thickness at about 1200 feet through the Susquehanna Valley south of Sunbury and north of Duncannon. Marked thinning of the Trimmers Rock occurs south of Duncannon and also south of Huntingdon, the same areas of thinning noted for the Brallier Member. Along the Blue Mountain trend thickness of the Trimmers Rock ranges from 700 to 1200 feet. Because of the present necessity of including mixed Trimmers Rock and Brallier lithologies under the term Trimmers Rock, the section is quite thick at Sunbury and Catawissa, totaling about 2400 feet at both localities. Part of this thickening is apparently related to the fact that the lowest red of the Catskill occupies a higher stratigraphic position than in sections farther south.

The significance of thickness variation in the Trimmers Rock results from statements which may be made about the earliest Catskill sediments. Thus it is demonstrated again that Catskill red beds occur pro-

gressively lower in the section (and presumably earlier) toward the east. But it is also shown from study of the shale units within the Trimmers Rock that the red beds occupy successively lower positions toward the south, a fact which requires serious revision in our interpretation of Late Devonian paleogeography. Rather than indicating a large classic delta or a series of small coalescing deltas along a north-south coastal plain, the evidence suggests a linear trough extending east-northeast through central Pennsylvania and receiving sediments from the south and east. Through time the red sediments built farther to the north and west, as indicated by the presence of red beds at higher stratigraphic levels in those directions. Indications of the southern boundary of this trough are offered by the very thin upper Devonian sections at Marysville and Saxton.

One of the most challenging aspects of a study of the Devonian of the Appalachians is the comparison of sections in widely separated areas. Such comparisons are particularly difficult to make because of regional differences in nomenclature and in methods of dividing the rocks. Throughout this paper, the writer has made reference to sections in states adjacent to Pennsylvania, in addition to noting lithologic similarities and dissimilarities. The concluding remarks given here will deal with the distribution of strata of Trimmers Rock lithology throughout the Appalachians, as understood from the sections studied and from several reconnaissance trips.

The Trimmers Rock Member of the Fort Littleton Formation is traceable at the surface into southeastern New York. As noted, the unit is exposed north of Port Jervis, where it consists of the main body and a lower tongue transitional downward into the lower Mount Marion Formation. The Mount Marion of the Catskill and Kaaterskill quadrangles has been described informally by Chadwick (1944, p. 104-112) as follows: 1) lower unit of poorly bedded sandstones; 2) middle unit of arenaceous shales; and 3) upper unit of heavier sandstones with "storm rollers." This sequence is closely similar to that at Port Jervis and in the Hess well. Whether the shales of the Port Jervis section are continuous with those of the Mount Marion in the Catskill and Kaaterskill quadrangles can only be established by field mapping, and because of glacial cover the possibility that this can be accomplished seems small.

The lower tongue of Trimmers Rock at Port Jervis extends westward together with the lower Mount Marion siltstones at least as far as Brodheadsville in western Monroe County where isolated outcrops of both rock types are present. The high escarpment bordering the Delaware River on the west from Port Jervis to Bushkill is held up by the resistant lower Mount Marion and the lower Trimmers Rock tongue. Westward from Bushkill to Brodheadsville both rock types are present but may not be mappable.

As noted previously, the Trimmers Rock is not traceable at the surface into the classic localities in central New York because younger rocks are present over much of the state boundary. Detailed studies undertaken by D. L. Woodrow in this region may provide some long-needed ties with the New York sections.

The outcrop belt of Trimmers Rock trends south-southwest from Pennsylvania into the panhandle of Maryland and thence into West Virginia and Virginia. Lithologic counterparts of the Trimmers Rock include part of the Chemung Sandstone and Parkhead Sandstone Members of the Jennings Formation in Maryland, and portions of the Chemung Formation and the Brallier Shale in West Virginia, and Virginia. Not all Chemung in these states is of Trimmers Rock lithology because the Chemung is commonly designated to include all rocks containing marine fossils, which, in many cases, occur well above the lowest red beds.

SUMMARY

The terms Chemung Group, Portage Group, Parkhead Sandstone Member and Losh Run Member are not considered valid in Pennsylvania because they cannot be utilized as rock-stratigraphic names.

The Trimmers Rock Member of the Fort Littleton Formation is expanded upward to include lithologically identical rocks previously designated Chemung, the top contact of the redefined Trimmers Rock being the lowest red beds of distinctive color or the Delaware River Flags. In Pike and Monroe Counties, rocks of Trimmers Rock lithology are transitional downward into the lower portion of the Middle Devonian Mount Marion Formation, and a thick shale interval well above the base of the Trimmers Rock may represent the Mahantango, Burket, Brallier, and Harrell. Thickness variations of both the Brallier and Trimmers Rock suggest that an area of relatively rapid accumulation trended east-northeast through central Pennsylvania during the Late Devonian, bordered on the south by a region of less-rapid accumulation.

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Faunas of the Mahantango Formation in South-central Pennsylvania

ABSTRACT

The wedge of clastic sedimentary rocks comprising the Mahantango Formation in south-central Pennsylvania is divisible into three units, namely, a lower shale member, a middle member of sandstone or siltstone and shale, and an upper shale member. Although each member has a rather distinctive fauna composed chiefly of brachiopods and pelecypods, nearly all of the faunas of the Mahantango Formation are dominated by *Tropidoleptus carinatus* or *Mucrospirifer mucronatus*. The faunas of these members change in composition across the area of study, some more noticeably than others.

Study of the distribution of species and larger taxa, particularly their comparative abundances, lateral and vertical persistence, and the study of composition of assemblages provide new insight into the faunas. Generally, the lower shale member is unfossiliferous, or nearly so; the middle member of sandstone and siltstone is characterized by a fauna that is not as diverse nor as laterally persistent as that of the upper shale member. The upper shale member has a particularly diverse fauna that persists throughout most of south-central Pennsylvania. Faunal differences between members are more pronounced in the Perry County area than in Huntingdon, Bedford, or Fulton Counties.

Comparisons between the faunas of the Mahantango Formation and the fauna of the Tully Member of the Harrell Formation are made and the stratigraphic relationships are discussed. Correlation of intraformational units of the Mahantango Formation of south-central Pennsylvania with the Hamilton Group of eastern New York are suggested tentatively on the basis of faunal evidence.

INTRODUCTION

General

The Mahantango Formation of the Hamilton Group has been described at twenty sections in south-central Pennsylvania (Fig. 1). Field study was concentrated in three areas, namely (1) Perry County and adjacent portions of Dauphin, Juniata, and Snyder Counties, where the type section for the Mahantango Formation is located and where the Montebello Sandstone Member is best developed; (2) Bedford and Fulton Counties, where the formation consists largely of siltstone and sandy shale; and

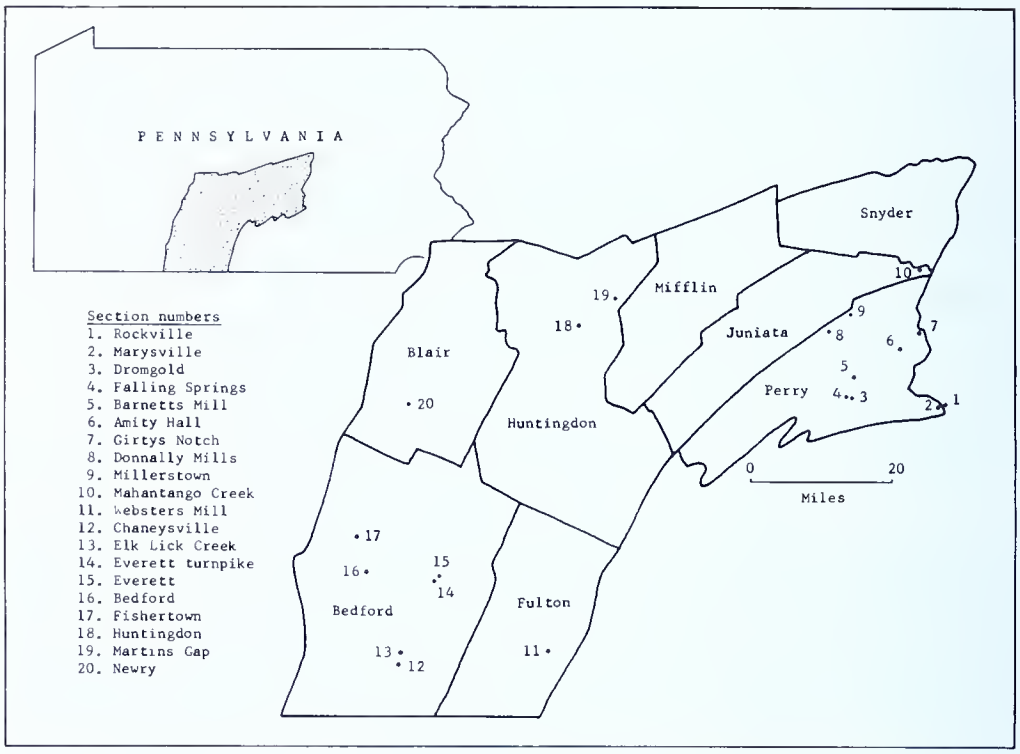

Figure 1. Location of the study area and described sections in south-central Pennsylvania.

(3) Huntingdon and Blair Counties, where the shale-claystone facies of the formation is best expressed.

From the described sections and from several additional localities, several thousand specimens of fossil invertebrates were collected and systematically studied (Ellison, 1961). The present paper presents an analysis of some of these data, and reports on a few of the broader aspects of the paleontology of this fossiliferous formation.

Stratigraphy

Three members of the Mahantango Formation are recognized in south-central Pennsylvania. These, essentially, are the same as those recognized by White (1883 and 1885), Claypole (1885), and Willard (1935a, 1935b, and 1939).

The lower shale member, termed the Gander Run Member in Bedford and Fulton Counties (Willard, 1935b), is less fossiliferous than the other members; its sparse fauna, dominated by *Leiorhynchus limitare*, has a definite Marcellus aspect.

Overlying the lower member in Perry County, the Montebello Member is a unit of partly cross-bedded and partly regularly bedded sandstone, of quartzose graywacke composition. It possesses a rather characteristic

fauna, and some species are very local in their distribution. Toward the west and south, this middle member is less sandy; in Bedford and Fulton Counties, it is represented by the Chaneysville Siltstone Member (Willard, 1935b), and in Huntingdon County, it is represented by two thin, ridge-forming units of siltstone separated by a unit of shale. At Chaneysville, the fauna of this member is particularly rich and varied.

The uppermost member of the Mahantango Formation in the area of study has been named the Frame Member in Bedford and Fulton Counties (Willard, 1935b). Inasmuch as this unit, especially the upper fossil zone (*Sulcoretepora zone*), can be traced across southern Pennsylvania, the term "Frame" is applicable throughout this area. For this paper, however, the term "upper shale member" will be used. Lithologically, this member is shale or claystone, in places with conspicuous beds of siltstone or sandstone. In most sections, the upper shale member is slightly calcareous, and in several sections, it includes nodules of limestone. Its fauna is distinctive, widespread, and includes more species than do the other two members combined.

The Tully in Pennsylvania now is recognized as a member of the Harrell Formation. Although the fauna of the Tully is quite characteristic, stratigraphically this member is closely related to the Mahantango Formation.

FAUNAL COMPOSITION AND DISTRIBUTION

General

The Mahantango fauna is composed of about 200 species and is dominated by two ubiquitous brachiopods, *Tropidoleptus carinatus* and *Mucrospirifer mucronatus*. These two gregarious species commonly occur in floods of specimens, either with or without other species. Despite their widespread occurrence, each of these species exhibits some stratification within its vertical range and, therefore, is of stratigraphic value.

In addition to these two species, several others are profuse enough to be considered major elements of Mahantango faunas. In order of decreasing abundance, these species are: *Chonetes scitulus* (brachiopod), *Longispina mucronatus* (brachiopod), *Sulcoretepora* cf. *S. incisurata* (bryozoan), *Protoleptostrophia perplana* (brachiopod), *Chonetes coronatus* (brachiopod), *Schuchertella variabilis* (brachiopod), *Mediospirifer audaculus* (brachiopod), *Trimerus (Dipleura) dekayi* (trilobite), *Fenestella* cf. *F. emaciata* (bryozoan), and *Palaeoneilo constricta* (pelecypod). It is interesting, and perhaps significant, that of these species, only *Longispina mucronatus* and *Sulcoretepora* cf. *S. incisurata* persist into the Tully Member of the Harrell Formation.

Lower shale member

The lower shale member has a fauna much smaller than either of the other two members of the Mahantango Formation in south-central Pennsylvania (Table 1). *Leiorhynchus limitare* (brachiopod), *Leptodesma rogersi* (pelecypod), and *Paleschara radiata* (bryozoan) are the characteristic faunal elements of this member which, in addition, includes 19 other species, most of which are pelecypods and brachiopods. Only *Leiorhynchus limitare* and *Leiopteria laevis*, however, are restricted to the lower shale member.

All of these species are rather diminutive; this may reflect optimum conditions as suggested by Phleger (1960) for shallow water Foraminifera, or it may reflect somewhat unfavorable conditions (Cloud, 1948). Whatever the specific conditions, the sediments most likely accumulated in a low-energy environment which made preservation possible. Such was not the case in Perry County where only one specimen (*Lingula*? sp.) has been found. An important factor in the destruction of the shells at that time may have been the oscillating, regressive shoreline that is suggested by the transitional nature of the contact with the overlying sandstone member.

Middle members

The Montebello and Chaneysville Members have faunas that are much more varied than that of the lower shale member (Table 1.) In the Perry County area, 17 species are restricted to the Montebello Member; of these *Subrensselandia claypolii* (brachiopod), *Rhipidomella penelope* (brachiopod), and three species of *Mediospirifer* are especially important.

In Bedford and Fulton Counties, the 77 species in the Chaneysville Member represent a somewhat more diverse fauna than that of the Montebello Member. Furthermore, the number of the individuals is considerably greater in the Chaneysville Member than in the Montebello Member. Nearly half of the species in the Chaneysville Member are restricted to that member in Bedford and Fulton Counties; among these *Chonetes marylandicus* (brachiopod), *Cornellites flabella* (pelecypod), and *Tentaculites attenuatus* (pteropod?) are particularly common.

The siltstone portions of the middle member in Huntingdon County are more fossiliferous than are the shale or claystone portions. Collectively, the fauna is composed largely of brachiopods (Table 1), and is characterized by several restricted species, including *Spinocyrtia granulosa* (brachiopod) and *Bembexia sulcomarginata* (gastropod). Both of these species are useful stratigraphic markers for the middle of the Mahantango Formation when mapping in this area.

Some appreciation of the lateral persistence of species found in the middle members may be gained by considering Table 2. As can be seen, some species are not restricted, but rather are found in all three general

Table 1. *Faunal distribution within members of the Mahantango Formation in south-central Pennsylvania.*

	Anthozoa		Bryozoa		Brachiopoda		Pelecypoda		Gastropoda		Cephalopoda		Pteropoda?		Trilobita		Ostracoda		Total numbers of species
	#	%	#	%	#	%	#	%	#	%	#	%	#	%	#	%	#	%	
Perry County																			
Upper shale member	2	2	11	9	44	35	35	37	11	9	4	3	3	2	5	4	13	10	128
Montebello Member	2	3	7	12	30	52	7	12	6	10	2	3	1	2	2	3	1	2	58
Lower shale member	0	0	0	0	1	100	0	0	0	0	0	0	0	0	0	0	0	0	1
Bedford-Fulton Cos.																			
Frame Member	6	9	4	6	25	38	15	23	6	9	2	3	0	0	3	5	5	8	66
Chaneysville Member	4	5	3	4	30	39	23	30	10	13	2	3	1	1	3	4	1	1	77
Gander Run Member	0	0	1	8	4	31	5	38	2	15	0	0	1	8	0	0	0	0	13
Huntingdon County																			
Upper shale member	9	9	13	13	31	31	23	23	5	5	4	4	1	1	6	6	9	9	101
Middle members	2	4	5	9	29	53	10	18	2	4	3	5	0	0	3	5	1	2	55
Lower shale member	1	5	1	5	7	37	9	47	0	0	1	5	0	0	0	0	0	0	19

Table 2. *Distribution of species, by number and percentage, to show lateral persistence of species within the middle and upper members of the Mahantango Formation in south-central Pennsylvania.*

	Middle members		Upper shale member	
	#	%	#	%
Found in only *one* area of study	58	51.5	65	41.5
Found in *two* areas of study	36	32.1	49	31.2
Found in all *three* areas of study	18	16.0	43	27.4

areas of study. Many species occur in two of the three areas; however, by far the largest number of species is restricted to one of the three areas. For the latter, significant differences must have existed between the environmental situations in each of these areas. Obviously, species having narrow ecological tolerances, or stenotypic species, are more informative, environmentally, than eurytypic species, such as *Tropidoleptus carinatus*, which have very broad environmental ranges.

Upper shale member

Throughout south-central Pennsylvania, the upper shale member is characterized by an extremely large and varied fauna. Although smaller in Bedford and Fulton Counties, the fauna consists of over 100 species in the other two areas of the present study. Important among species typical of this member are *Mucrospirifer mucronatus* in the lower part, and, in the upper part, *Sulcoretepora* cf. *S. incisurata, Schuchertella variabilis, Douvillina inaequistriata* var. *immatura* (brachiopod), *Delthyris sculptilis* (brachiopod), *Pustulatia pustulosa* (brachiopod), *Phacops rana* (trilobite), *Greenops boothi* (trilobite), and numerous species of pelecypods and ostracods. The Perry County area is somewhat different from the other areas in having proportionately fewer corals and more pelecypods.

Table 2 shows the lateral persistence of species of the upper shale member within the general area of study. Although most of the species in this member are restricted to one area, a sizable number occur in two areas, and a significant number is found in all three areas. This suggests that bottom and water conditions were more uniformly widespread during deposition of the upper shale member than during deposition of the middle members of the Mahantango Formation.

Tully Member of the Harrell Formation

The fauna of this member has numerous species in common with that of the upper shale member of the Mahantango Formation; several species, however, do appear for the first time in the Tully. In south-central Pennsylvania, 29 species have been identified from the Tully, seven of which

are unique to the Tully. The latter, including *Hypothyridina venustula* (brachiopod), *Emmanuella pennsylvanica* (brachiopod), *Echinocoelia ambocoeloides* (brachiopod), and *Leiorhynchus mesacostale* (brachiopod), are found chiefly in the limestone phase of the Tully Member. At Barnetts Mill, in Perry County, situated between Mahantango assemblages with *Pustulatia pustulosa* is an assemblage of *Leiorhynchus mesacostale* and *Echinocoelia ambocoeloides* that is suggestive of the Laurens Member of the Tully Formation in New York. Indeed, the fauna of the *Sulcoretepora* zone in the upper shale member of the Mahantango is strikingly similar to that of the West Brook Member of the Tully Formation in New York. These two units contain common species of corals, bryozoans, brachiopods, molluscs, and arthropods, in abundance; however, the West Brook Member contains *Hypothyridina venustula* and lacks *Pustulatia pustulosa*. The Mahantango and the Tully certainly will prove to be more intimately related than previously supposed, when additional stratigraphic details have been assembled and studied. Further work on this particular question is now in progress.

INTERSPECIFIC ASSOCIATIONS

Fager and McGowan (1963) group species of zooplankton by means of an "index of affinity"; these groups are then related to water masses in the Pacific Ocean. Such an index, to quote Fager (1957, p. 589), "provides an objective measure for the word 'frequently' in the statement 'these species frequently occur together'." Implicit in the method of Fager and McGowan is the assumption that the probabilities of the occurrence of the two species are related to the sum of their occurrences rather than to the total number of samples collected. This contrasts with other proposed indexes modeled after the chi-square test in which undue emphasis is placed on samples not containing either of the two species being compared. The revised formula for the index of affinity is (Fager and McGowan, 1963):

$J/\sqrt{Na \cdot Nb} - 1/2\sqrt{Nb}$ where: J is the number of joint occurrences;
Na is the number of occurrences of "a";
Nb is the number of occurrences of "b";
and Nb is greater than Na.

Indexes of affinity have been calculated for many pairs of species in the Mahantango Formation. Although Fager and McGowan arbitrarily use 0.50 as their breakpoint for significant vs. non-significant association, 0.30 was chosen for the present study. Few of the calculated values are greater than 0.50. In order to be grouped, species must have relatively high indexes of affinity for every other species in that group. For example, in a group of four species, A, B, C, and D:

A must have a high affinity for B, and for C, and for D;
B must have a high affinity for C, and for D; and
C must have a high affinity for D.

Such a procedure tends to eliminate chance associations that may result from using a low cutoff point. By using this technique, several groups of interrelated species have been established within the Mahantango Formation. These groups were erected on the basis of data taken from within members and are given in Table 3.

Table 3. *Interspecific association of species in the Mahantango Formation of south-central Pennsylvania.*

Upper shale member
- Group I—*Fenestella* cf. *F. emaciata* (bryozoan)
  Sulcoretepora cf. *S. incisurata* (bryozoan)
  Schuchertella variabilis (brachiopod)
  Douvillina inaequistriata var. *immatura* (brachiopod)
  Phacops rana (trilobite)
- Group II—*Cypricardella bellastriata* (pelecypod)
  Nucula bellistriata (pelecypod)
  Nuculites oblongatus (pelecypod)
  Orthonota parvula (pelecypod)
  Bembexia laevis (gastropod)

Chaneysville Member
- Group III—*Rhipidomella vanuxemi* (brachiopod)
  Protoleptostrophia perplana (brachiopod)
  Delthyris sculptilis (brachiopod)
  Athyris spiriferoides (brachiopod)
- Group IV—*Chonetes scitulus* or *Chonetes marylandicus* (brachiopods)
  Longispina mucronatus (brachiopod)

Montebello Member
- Group V—*Mediospirifer audaculus* (brachiopod)
  Cornellites flabella (pelecypod)
  Tentaculites attenuatus (pteropod?)

Lower shale member
- Group VI—*Leiorhynchus limitare* (brachiopod)
  Leptodesma rogersi (pelecypod)
  Paleschara radiata (bryozoan)

It is interesting to note that, although Group V maintains its identity for some 100 stratigraphic feet at Rockville, this association is not present about one mile away, in the section at Marysville. This may indicate persistent but local environmental conditions; or it may be an indication of discontinuities in assemblages such as might be expected in a marginal high-energy environment; or it could result from inadequacies of sampling. Some of the other associations are more extensive, particularly those of the lower and upper shale members. Group VI extends from Bedford to Martins Gap, in Huntingdon County, and with modifications to Websters

Mill in Fulton County. Group II, characterized by *Bembexia laevis* and, in some sections, by *Paracyclas lirata* (pelecypod), is distinctive of the basal portion of the upper shale member in Perry County. Within the Chaneysville Member, groups III and IV both are found in four sections in the Bedford-Fulton-Huntingdon area. As yet these interspecific associations have not been tested against environmental factors.

FAUNAL ZONES

Faunal zones of the Mahantango Formation have provided a useful means for establishing intraformational relationships within the area of study. Some zones are, stratigraphically, more useful than others, by virtue of their lateral persistence, vertical restriction, and relative predictability. Thus, for example, the *Sulcoretepora* zone of the upper shale member is found at the top of the formation in nearly every section and, therefore, is considered to be essentially continuous throughout south-central Pennsylvania. The more important faunal zones and their related interspecific associations are presented in Table 4.

Table 4. *Major faunal zones of the Mahantango Formation in south-central Pennsylvania.*

Upper shale member
- *Sulcoretepora* zone—group I association
- Upper *Tropidoleptus* zone
- Lower *Tropidoleptus* zone—in Perry County only
  - *Rhipidomella vanuxemi* zonule
  - *"Spirifer" tullius* zonule
- *Mucrospirifer mucronatus* zone—group II association in Perry County

Middle members
- *Mucrospirifer mucronatus* zone—group III and IV associations in Bedford and Fulton counties
- *Bembexia* fauna and *Spinocyrtia* fauna—in Blair and Huntingdon counties
- *Mediospirifer* zone—group V association
  - *Chonetes coronatus* zonule—in Perry County only

Lower shale member
- *Leiorhynchus* fauna—group VI association in Huntingdon, Bedford, and Fulton counties.

DISTRIBUTIONAL CHARACTERISTICS OF FAUNAL ELEMENTS

The taxa in which the most significant changes take place between members, as well as between areas are shown in Table 1. In the Perry County area there is a drastic drop in brachiopods from the Montebello Member to the upper shale member, accompanied by an increase in pelecypods and ostracods. Such a change in faunal composition, therefore, may reflect a general shift of environmental conditions to a situation in some way more favorable for deposit feeders. Finer sediments usually are richer in organic detritus, which is the bread and butter of deposit feeders. Bader (1954) has shown that the density of pelecypods is directly

proportional to the amount of organic matter in the sediment, provided that decomposition remains below a certain level and that anaerobic conditions are not produced. It seems reasonable to conclude that the proliferation of pelecypods in the upper shale member, especially in Perry County, is at least partly related to the accumulation of clays rich in nonrefractory organic detritus, along with a relatively low rate of bacterial decomposition of this organic material. Of the pelecypods involved in the increase, the paleoconchs and the taxodonts are most important, and living species of some taxodont genera such as *Nucula* are known to be deposit feeders (Mitsukuri, 1881).

Figure 2 shows the persistence of species between members within areas. Differences between areas as shown in this figure may not be significant, but they may indicate tendencies. Species in Perry County tend to be confined to one of the three members, particularly the upper shale member. This is less true of the other two areas. A sizable number of species in Bedford and Huntingdon Counties tend to appear in two or three members. This would lead one to conclude that environmental differences between members are not as pronounced in Bedford and Huntingdon Counties as they are in Perry County. One of the most significant changes in the Perry County area is the decrease in the number of spiriferid species from the Montebello Member into the overlying member. These "psammophilic" species, such as *Paraspirifer acuminatus* and *Mediospirifer bellitropis*, with their thick shells, must have been well adapted to marginal high-energy conditions; that the sea floor during Montebello deposition was an area of continually shifting sands is evidenced by the abundance of cross-bedding and channeling in that member. A chi-square test revealed no significant relationship between presence of fossils and the presence or absence of cross-bedding.

FAUNAL CORRELATION OF THE MAHANTANGO FORMATION WITH FORMATIONS OF THE HAMILTON GROUP IN NEW YORK

Faunal correlation of the Mahantango Formation with formations of the Hamilton Group in New York is based primarily on the occurrence of four species: *Paraspirifer acuminatus*, *Fimbrispirifer venustus*, *Pustulatia pustulosa*, and *"Spirifer" tullius*.

Paraspirifer acuminatus occurs in the lower part of the Montebello Member of the Mahantango Formation in Pennsylvania, and in the lower part of the Panther Mountain Sandstone of the Hamilton Group in eastern New York. Inasmuch as its disappearance above this level apparently is not related to any environmental changes, it is thought to represent approximately the same point in time at both places.

One of the species most distinctive of the Centerfield Member of the Ludlowville Formation in New York is *Fimbrispirifer venustus*, although it

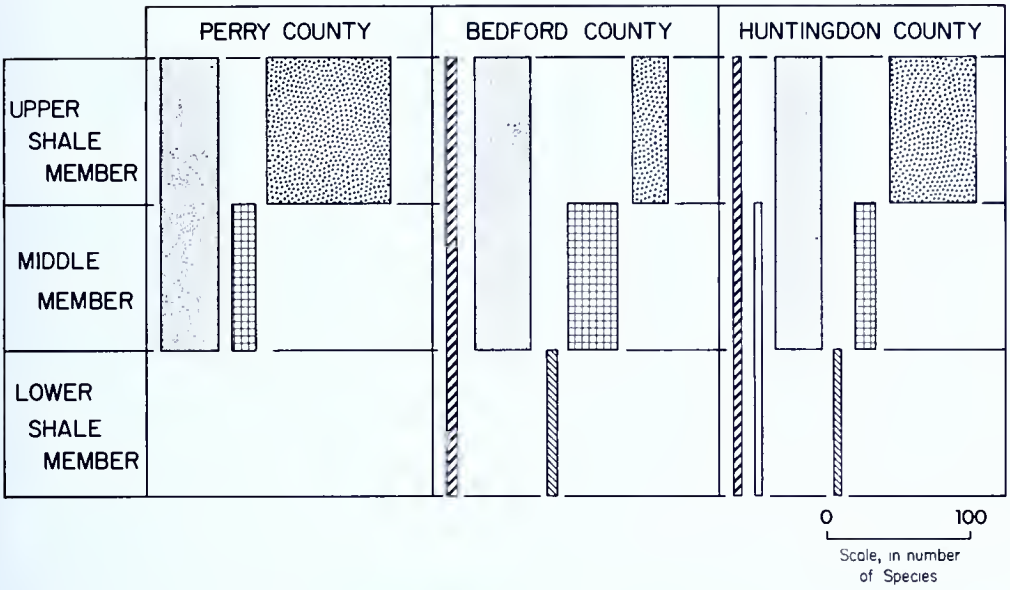

Figure 2. Stratigraphic persistence of species in the Mahantango Formation of south-central Pennsylvania.

also is found in the Portland Point Member of the Moscow Formation. Specimens of this species have been identified from the Chaneysville Member in Bedford County, in a sequence within the *Mediospirifer* zone. On this basis, and also because the *Mediospirifer* zone is rich in coral species in Perry County, this particular sequence has been correlated with the Centerfield of New York.

The persistence of the relatively thin *Sulcoretepora* zone in the upper shale member is one of the most important stratigraphic features of the Mahantango Formation in south-central Pennsylvania, extending at least from Chaneysville and Websters Mill in the more southerly part of the state to Girtys Notch on the Susquehanna River. Within this zone, the *Pustulatia pustulosa* zonule is less persistent, but it is strong indication of a correlation with the Windom Member of the Moscow Formation in New York, where that species is particularly characteristic. Another diagnostic species, *"Spirifer" tullius*, also is found both in the upper shale member of the Mahantango in Pennsylvania and the Windom Member of the Moscow in New York.

On these faunal bases and on the basis of additional stratigraphic data, it has been suggested (Ellison, 1961) that the Mahantango Formation in south-central Pennsylvania is approximately time-equivalent with the Skaneateles, Ludlowville, and Moscow formations of the Hamilton Group in New York.

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Stratigraphy between Tioga Metabentonite and Pocono Formation along Allegheny Front in Maryland and West Virginia

ABSTRACT

Middle and Upper Devonian strata exposed along 75 miles of the Allegheny Front outcrop belt were interpreted from sections at these 11 localities, listed from north to south: Corriganville, LaVale, and Pinto in Maryland, and Keyser, U.S. Route 50, Scherr, old Eureka School, Hopeville, Mouth of Seneca, Ketterman Knob, and Spruce Knob road in West Virginia. About four-fifths of the stratigraphic sequence is exposed in the portions of the interval studied in the sections, which provides sufficient control for analysis of facies changes. Fossils can be used for gross age determination, but the distribution of most species appears to be influenced by facies. More precise correlation in this area of changing facies is based on intertonguing strata, position in stratigraphic sequence, and thicknesses of stratigraphic intervals as determined by plane table measurements. The sections are foreshortened by thrust faulting at Corriganville, LaVale, Mouth of Seneca, and Ketterman Knob.

An influx of sand and silt in late Hamilton time produced a coarser clastic unit (Mahantango Formation) between the Marcellus and Harrell black shales in the area from Corriganville to Route 50. From Scherr to Hopeville the Mahantango Formation consists of thickly laminated, calcitic shale facies. South of Hopeville the Harrell and Marcellus shales cannot be separated with confidence. Near the middle of the Harrell Shale at Corriganville, Keyser, and Route 50, very shaly, lenticular limestone occurs, probably correlative with the Tully Limestone in wells in Garrett and Tucker Counties west of the outcrop belt.

The major influx of Devonian clastics began with the Brallier Formation, and filled the depositional basin to above sea level, culminating in Catskill terrestrial deposits in latest Devonian time. The thickest deposition along the outcrop belt was at Keyser, where turbidity current action was prominent. Upper Devonian strata become markedly thinner and finer southwestward from Keyser. Conglomeratic beds are found in an interval 1000–1900 feet thick near the top of the Chemung Formation. The lowest red bed in the Chemung occurs at progressively higher stratigraphic positions from north to south. At Route 50, terrestrial deposition occurred late in Chemung time. Marine red beds formed at the same time in the other sections. Afterward the sea returned before the major nonmarine deposition (Catskill Formation) in latest Devonian time. The Catskill Formation is 1650 to 2200 feet thick, thinning slightly toward the southwest.

INTRODUCTION

The writer is cooperating with the West Virginia Geological Survey in a study of post-Oriskany Devonian strata along Allegheny Front from

the Maryland-Pennsylvania boundary southwestward to Bluefield, W. Va. Field work has progressed 75 miles along strike from Corriganville, Md., to the Forest Service road ascending Spruce Knob in Pendleton County, W. Va. Many new stratigraphic divisions have been traced across the area, but numerous facies changes also occur along the outcrop belt.

Detailed sections were measured with plane table control at 11 localities (Figure 1) during 1961 and 1962 with the aid of Orville D. Naegele of Fairmont State College, W. Va. This work revealed that many sections along Allegheny Front are cut by thrust faults. A more detailed description of the stratigraphic and structural interrelations has been prepared (Dennison and Naegele, in press), and most of the stratigraphic information presented here is summarized from this longer paper. During 1963 field work is being continued southward into Highland County, Va., and westward to Pocahontas County, W. Va., with the assistance of Jack W. Travis of Michigan State University.

Brief comparison will be made of outcrops with well data obtained a few miles west of Allegheny Front.

PREVIOUS WORK

Earlier treatments of regional stratigraphic variations along this part of Allegheny Front are restricted to publications of the geological surveys of Maryland and West Virginia. The classic volumes on the Devonian of Maryland (Prosser and others, 1913; Prosser and Swartz, 1913) serve as a basis for extending detailed stratigraphy southward to West Virginia. The present study also contributes considerable new information on the Maryland localities. Exposures in West Virginia were described briefly in the reports on Mineral and Grant Counties (Reger, 1924) and Pendleton County (Tilton and others, 1927). Regional aspects of these strata were considered by Woodward (1943). Only two of the sections measured for the present paper were previously described with reliable detail and precision.

STRATIGRAPHY

The stratigraphic nomenclature used here conforms to current usage by the West Virginia Geological Survey. Thickness of the rock-stratigraphic units are summarized as follows:

Catskill ("Hampshire") Formation. 1650 to 2200 feet.
Chemung Formation. 1670(?) to 3880 feet.
Brallier Formation. 647 to 2170 feet.
Harrell Shale. 32 to 309 feet.
Tully Limestone. 0.0 to 1.7 feet.
Hamilton Group
  Mahantango Formation (Hamilton Formation of older W. Va. literature). 0 to 600 feet.

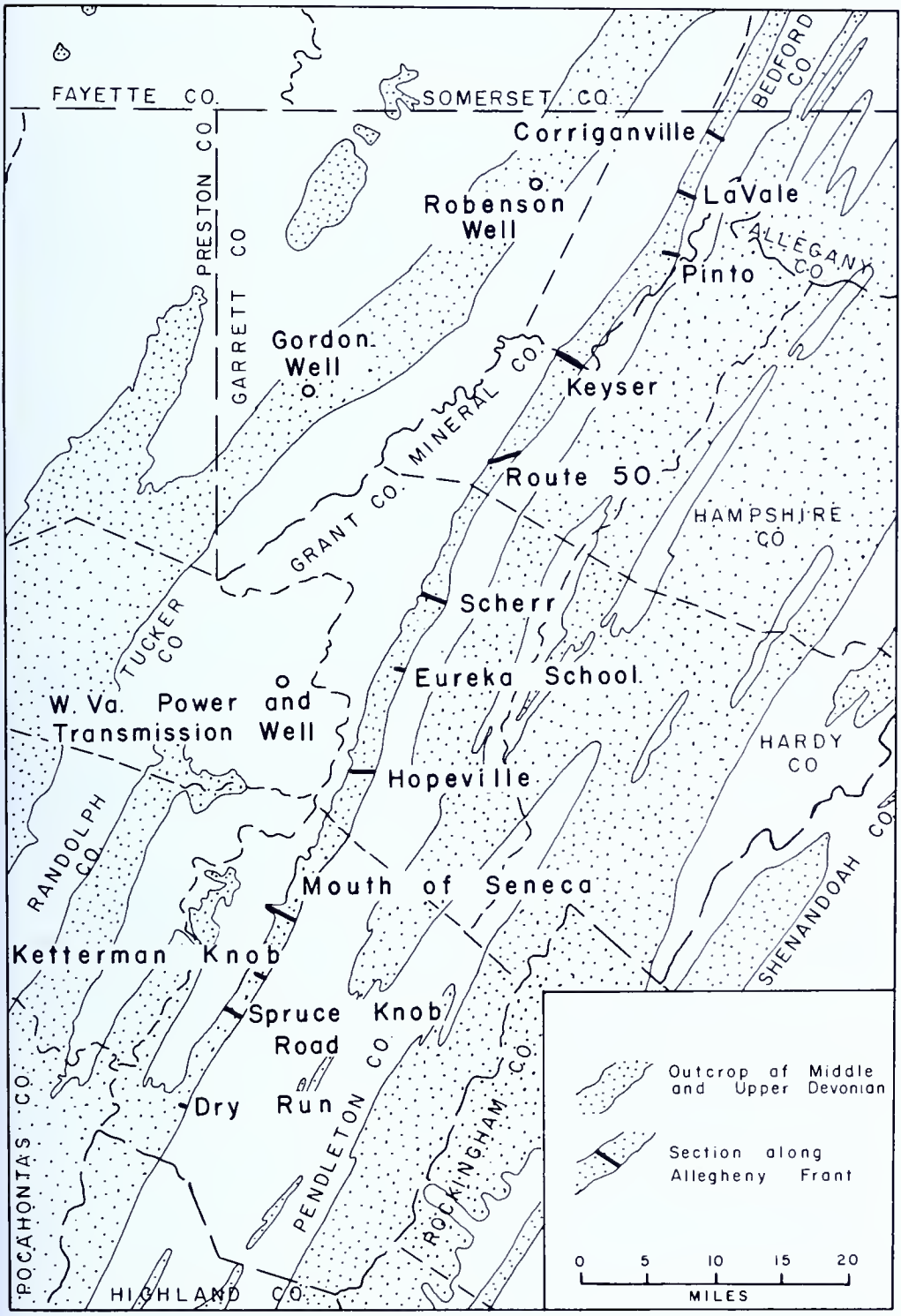

Figure 1. Location of data points described in this study.

Marcellus Shale. 77 to 855 feet.
Onesquethaw Stage
Tioga Metabentonite. 2 to 6 feet.
Needmore Shale. 126 to 190 feet.

The approximate geologic ages of these units are known paleontologically relative to the New York standard Devonian section (Woodward, 1943). Field observations suggest a close relationship between fossil types and specific lithologies within a given formation. Fossil types probably are greatly affected by sedimentary environment; therefore, caution must be used in deciphering stratigraphic age on the basis of fossils alone. It is believed that precise time relations in sections as closely spaced as those studied can best be established in detail by intertonguing lithologies, local stratigraphic sequence, and thickness of stratigraphic intervals, supplemented by paleontologic dates as a gross independent check. Detailed fossil collections were made at all sections, and ultimately it is hoped that facies effects on the faunas can be separated from temporal control of the fossils.

Location of Sections

The locations of the 11 sections shown in Figure 1 are as follows:

1. Corriganville, Md. In the town, along the Western Maryland Railway, along Route 36 in valley of Jennings Run. Section is not faulted appreciably northeast of Jennings Run, but about 1200 feet of the Brallier Formation is omitted by faulting along the railway.
2. Near LaVale, Md. Along valley of Braddock Run in cuts beside U. S. Route 40, in excavations for shopping centers, and in abandoned railroad cuts. In this vicinity the Marcellus Shale is generally in fault contact with the upper part of the Brallier, but the Harrell and Mahantango formations are exposed in excavations behind the State Police station in LaVale.
3. Near Pinto, Md. Exposures in fields permit approximate thickness determinations of Harrell and Mahantango formations.
4. Keyser, W. Va., and vicinity. Nearly complete exposures from southwest part of Keyser to cuts along Route 46 in valley of North Branch of Potomac River.
5. Along U. S. Route 50 on Allegheny Front near Claysville, W. Va. Part of section along unnamed tributary of New Creek. Probably about 850 feet of middle part of Brallier Formation is omitted by faulting.
6. Scherr, W. Va. Exposed chiefly in cuts along W. Va. Route 42.
7. Eureka School (abandoned), Grant County, W. Va. Exposures of Mahantango and Harrell formations beside farm pond.
8. Near Hopeville Gap, Grant County, W. Va. Along valley of Big Run and along Forest Service road leading up Allegheny Front toward Dolly Sods.
9. Mouth of Seneca, Pendleton County, W. Va. Along U. S. Route 33 and valley of Seneca Creek. Numerous minor faults occur in Oriskany through Chemung formations.
10. Near Ketterman Knob, Pendleton County, W. Va. Along U. S. Route 33, 5.4 road miles southwest of Mouth of Seneca. Harrell and Braillier formations cut by numerous minor faults, probably producing a thinning of 200 feet in apparent stratigraphic thickness of the Brallier.
11. Along Forest Service road leading from U. S. Route 33 toward Spruce Knob, 1 mile northeast of Judy Gap, Pendleton County, W. Va. No significant faulting observed.

About four-fifths of the stratigraphic sequence generally is exposed in the interval studied at these sections.

Data from the following well sites (Figure 1) can be compared with outcrops a few miles to the east along Allegheny Front.

1. Robeson No. 1 Well. By Superior Oil Co. Well F-66 of Amsden (1954, plate 3). Upper part of Chemung Formation through Oriskany Sandstone.
2. Gordon No. 1 Well. By Snee and Eberly. Well F-22 of Amsden (1954, plate 3). Brallier (Woodmont) through Helderberg sample descriptions.
3. W. Va. Power and Transmission Co. (Kaemmerling, Trustee) No. 1 Well. By the Ohio Oil Co. Interpretation modified after sample descriptions of Catskill through Oriskany interval by Martens (1945, p. 557–567).

Description of Units

The following thickness and lithologic descriptions are based on the assumption that the structure of each measured section has been interpreted correctly. Structural interpretation depends partly on an assumed knowledge of stratigraphy. Interpretation is tenuous where both stratigraphy and structure might be variables. Faulting has complicated measurement of the thickness of the Needmore through Brallier Formations in some sections, as will be indicated elsewhere in this paper.

Thicknesses of post-Oriskany Devonian formations along Allegheny Front are summarized in Figure 2. Willard's (1939) thicknesses for the strata in Bedford County, Pennsylvania, are presented for comparison. Note the use of vertical solid lines in all stratigraphic sections to indicate those beds which are exposed and described in detail.

Onesquethaw Stage

Between Spruce Knob and Corriganville the Onesquethaw Stage consists almost entirely of Needmore Shale. The thin Tioga Metabentonite forms the top boundary of the stage as designated by Dennison (1961, p. 10).

The Needmore Shale marks the introduction of mud into the Appalachian geosyncline accompanying rising of land to the east as the Acadian orogeny began. Genetically the Needmore is related to the clastics of the Hamilton Group, so its stratigraphy is summarized in Figure 3. The Needmore Shale can be divided from bottom upward into the Beaver Dam black shale subfacies, calcitic shale subfacies, and calcitic shale and limestone subfacies (Dennison, 1961). A zone of chert nodules about 0.2 foot thick occurs near the base of the calcitic shale subfacies. This is thought to be approximately contemporaneous along the outcrop belt, representing a time of eastward extension of the silica depositional environment which formed the main mass of Huntersville Chert encountered in the Robeson, Gordon, and W. Va. Power and Transmission Co. wells.

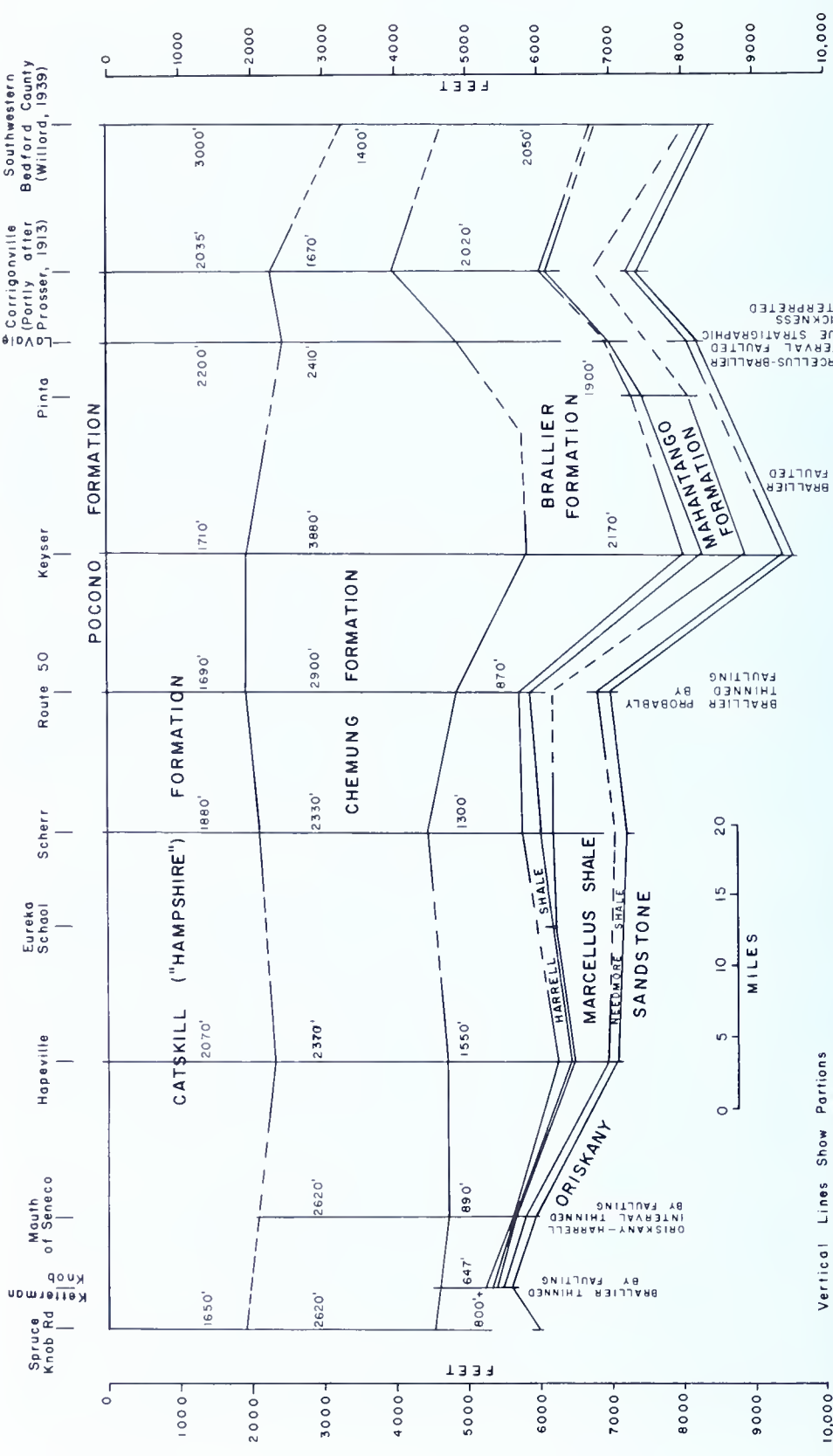

Figure 2. Stratigraphic cross section summarizing Middle and Upper Devonian along Allegheny Front.

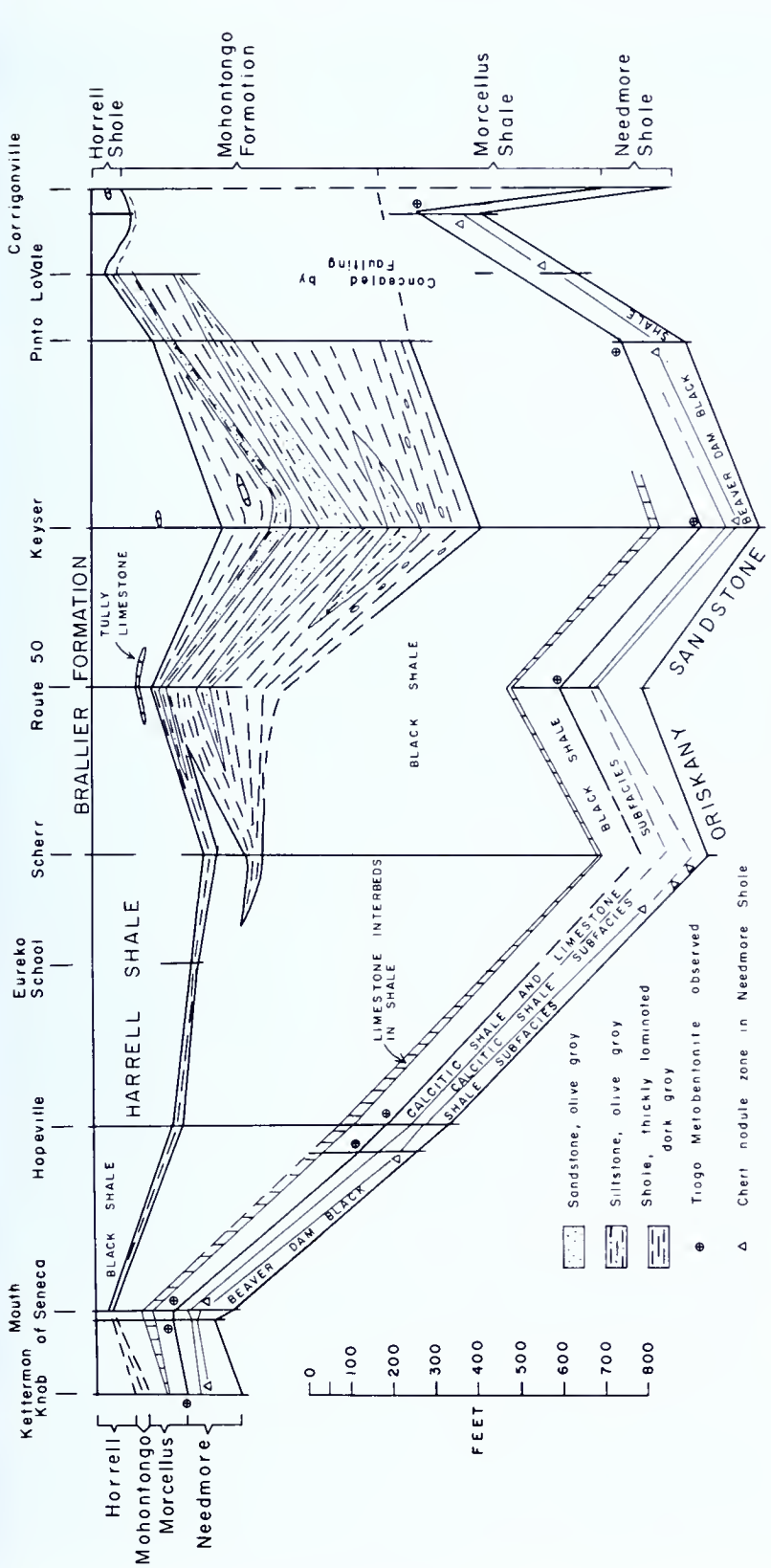

Figure 3. Details of stratigraphy of Needmore-Harrell interval along Allegheny Front.

The Tioga Metabentonite consists of thinly laminated shale characterized by a brownish-gray color when weathered and by sand-size mica flakes. The source volcano probably was in the Piedmont of central Virginia (Dennison, 1961, p. 39). The metabentonite is 2–3 feet thick near Keyser and Corriganville, and thickens to 4–6 feet in Pendleton County. The writer has recognized the Tioga Metabentonite a few feet below the top of the Selinsgrove Limestone at Selinsgrove Junction near Sunbury, Pa., so this volcanic deposit promises to be useful in deciphering Onesquethaw outcrops throughout central Pennsylvania.

Hamilton Group

For many years the term "Hamilton" has been used in West Virginia and Maryland for siltstone, silty shale, and sandstone which occupy the stratigraphic interval between the Marcellus and Harrell shales. Use of Hamilton in this sense differs from its current nomenclature in New York and northern Pennsylvania, where the Hamilton Group includes the Marcellus, Skaneateles, Ludlowville, and Moscow formations. The term Mahantango Formation is used for the post-Marcellus beds of the Hamilton Group in southern Pennsylvania. Mahantango lithology can be traced from Pennsylvania across Maryland into West Virginia, so the writer prefers to recognize the Marcellus and Mahantango Formations in West Virginia, and to consider them collectively as the Hamilton Group. This brings West Virginia usage more into conformity with the stratigraphic nomenclature of other states.

The *Marcellus Shale* consists almost entirely of grayish-black, thinly laminated, noncalcitic, pyritic shale which weathers yellowish gray and platy. From the Keyser area southward to Ketterman Knob the base of an apparently persistent zone of limestone interbedded with shale occurs 100 to 40 feet above the base of the Marcellus, with the interval gradually decreasing southward (Figure 3). Northeast of Keyser the expected position of this limestone zone is covered by weathering debris or concealed by faulting. It is about 15 feet thick in the Robeson well. In the Keyser area the limestone and shale zone is conspicuous at Forge Hill (20 feet) and along U. S. Route 220 near Rock Hill. Only scattered limestone concretions occur at this position at Twenty-first Bridge. The limestone is incompletely exposed at Route 50 and Scherr. Fifteen feet of limestone with shale occurs at Hopeville. In the black shale between Tioga Metabentonite and Brallier Formation, limestone with shale interbeds occurs at the same general stratigraphic position 0.3 mile southwest of Mouth of Seneca (29 feet thick) and at Ketterman Knob (6 feet thick). Limestone and shale in the Marcellus is 30 feet thick in the Gordon well, and 5 feet thick in the W. Va. Power and Transmission Co. well.

Marcellus Shale is very incompetent structurally, and its true thickness is difficult to measure. In the Keyser area the Marcellus thickness varies from 320 to 640 feet, and is probably normally about 520 feet. It is mostly covered at Pinto and Corriganville and is partly omitted by faulting at LaVale. The thickness of the Marcellus is estimated at Route 50, because the exact base of the Mahantango Formation is concealed. Abnormally thick Marcellus at Scherr results from a facies change with the Mahantango Formation as shown in Figure 3. At Hopeville the Marcellus is 465 feet thick, and it thins to about 77 feet at Ketterman Knob.

The *Mahantango Formation* consists of thickly laminated shale, siltstone, very fine sandstone, and a little limestone. Lithologic changes along strike are portrayed in Figure 3. The Mahantango Formation is about 600 feet thick at Keyser, where a good composite section is obtainable. There it consists mostly of silty shale, except for two prominent zones of siltstone and sandstone near the top of the formation. These two sandy zones can be recognized northward to Corriganville. Scattered siltstones also occur about a third of the distance above the base of the formation at Keyser. The Mahantango Formation becomes finer grained southwestward. The two upper sandy zones have changed to siltstone at Route 50. At Scherr they have changed to two units of thickly laminated, dark-gray shale in the midst of grayish-black, thinly laminated shale of Marcellus-type lithology. The lower part of Mahantango-age beds at Keyser have changed to Marcellus facies at Scherr. Only the upper coarse clastic tongue persists southwestward to Eureka School and Hopeville, where the Mahantango consists of thickly laminated shale facies.

The Mahantango Formation cannot be recognized with certainty one mile south of Hopeville or southwestward, although it possibly is represented by 37 feet of thickly laminated, calcitic shale with some limestone at Ketterman Knob (indicated in Figure 3; however, this limestone might be of Tully age).

Limestone occurs in the Mahantango Formation in some exposures. A limestone bed is prominent in the upper coarse clastic (thickly laminated shale) unit at Eureka School and Hopeville. A limestone bed occurs 110 feet below the top of the Mahantango Formation in the lower siltstone unit in the Route 50 section. In an excavation behind the general store at Dawson, a shaly, coral biostrome occupies the interval 75–89 feet beneath the top of the Mahantango Formation, occurring a few feet above the upper sandy unit in the Mahantango.

Harrell Shale

Harrell Shale is distinguished from the adjacent Mahantango and Brallier Formations by its dark color and by a general absence of siltstone. The Harrell is mostly dark- to very dark-gray, thinly laminated shale with some thickly laminated shale. Figure 3 shows the general thickness

distribution of the Harrell Shale. It is 94 feet thick 1.8 miles southwest of Corriganville, but only 32 feet thick in the excavation behind the State Police station at LaVale. It is probably thinned at LaVale by structural attenuation. At Pinto the Harrell is 140 feet thick. The Harrell thickness is 309 feet at Keyser, with the base concealed, but this figure probably represents nearly the complete formation. The Harrell is 142 feet thick at Route 50, 261 feet thick at Scherr, and 186 feet thick at Hopeville. It is probably 30 feet thick at Mouth of Seneca, and 90 feet thick at Ketterman Knob. The interval between the Tioga Metabentonite and Brallier Formation is nearly all black shale at the last two localities, and the exact base of the Harrell is not known certainly. Some geologists might prefer to use the Virginia name Millboro Shale for these dark shales, rather than attempt to divide them into Marcellus, Mahantango and Harrell equivalents.

Tully Limestone

Outcrops of Tully Limestone are previously not reported in West Virginia and Maryland, although it is encountered in wells a few miles west of Allegheny Front. In the Route 50 section at 38 feet above the base of the Harrell Shale there occurs 1.7 feet of interbedded medium-dark-gray limestone and calcitic shale which is tentatively identified as Tully Limestone. The occurrence of this limestone in the midst of black shale corresponds well to the position of the "Tully Limestone" encountered in the Gordon well 16 miles west of the Route 50 section.

A limestone concretion noted near the middle of the Harrell Shale at Corriganville (Figure 3) might represent a tongue of the Tully depositional environment. At O'Neil Gap 3 miles east of Keyser at the base of Knobly Mountain 0.2 foot of medium-dark-gray limestone 118 feet above the base of the Harrell Shale (237 feet thick there) is probably also Tully.

Brallier Formation

The Brallier Formation consists chiefly of medium-dark-gray, light-olive-gray-weathering, thickly laminated shale interbedded with considerable siltstone and containing scattered sandstone beds in the top part from Keyser northward. The upper fourth or fifth of the formation generally has thicker beds of coarser clastics than the lower portion. General thickness relations of the Brallier are shown in Figure 2.

Faulting occurs in the Brallier at several sections. In the LaVale area most of the Brallier thickness is omitted by faulting. Probably about 850 feet of Brallier is concealed by faulting within the formation at Route 50. The 870 feet recorded in Figure 2 is the apparent thickness exposed there, rather than the true stratigraphic thickness before faulting. The fault is visible in aerial photos. At Mouth of Seneca and Ketterman Knob numerous small faults offset siltstone beds in the Brallier. These faults

probably cause about 200 feet of stratigraphic thinning of the formation at Ketterman Knob.

Chemung Formation

The Chemung is the most varied formation in the Devonian delta sequence, consisting of brownish-, reddish-, and medium-gray siltstone and sandstone along with some conglomerate, conglomeratic sandstone, and medium-dark-gray shale.

The Chemung Formation can be divided into an upper and lower portion with markedly different lithologies (Figure 4). The lower part of the Chemung consists of mostly siltstone with considerable shale and some sandstone in beds less than 2 feet thick (all olive gray- to light olive gray-weathering with the exception of some brownish-gray "red beds" in the basal 50 feet of the Chemung at Corriganville and LaVale). The upper part of the Chemung contains abundant sandstone beds several feet thick, siltstone, a little shale, several lenticular beds of conglomerate, and many red beds. The contact of the two divisions is very distinct, and it approximately coincides with the position of the lowest conglomerate within the Chemung from Mouth of Seneca northward.

From Corriganville southward to Spruce Knob road, an interval consisting of mostly thickly laminated shale with some siltstone and almost no sandstone occurs immediately beneath the abrupt base of the upper sandy division of the Chemung Formation.

The lowest "red beds"occur somewhat above the lowest conglomerate and massive sandstone in the formation (with the exception of the few "red beds" at the base of the Chemung in the LaVale and Corriganville areas). Up to the base of the lower massive sandstone unit the "red beds" are actually brownish gray and contain marine fossils. At Mouth of Seneca the interval between the lowest "red bed" and the lowest conglomerate is affected by poorly exposed complex folding, and the great thickness of the interval suggests that the structure may be improperly deciphered there in that portion of the Chemung. Conglomerate and conglomeratic sandstone in beds up to 13 feet thick occur scattered from the top of the formation downward to the position marked "lowest conglomerate" in Figure 4.

From Route 50 southward two prominent yellowish-gray-weathering sequences of mostly massive sandstone occur within the Chemung. These are designated in Figure 4 as upper massive sandstone and lower massive sandstone. These units probably can be recognized as far north as LaVale, and possibly to the Pennsylvania border. Both contain the *Cyrtospirifer* assemblage. The most conspicuous red beds in the Chemung Formation occur between the upper and lower massive sandstones. At Route 50 this interval is mostly grayish-red sandstone and siltstone, and

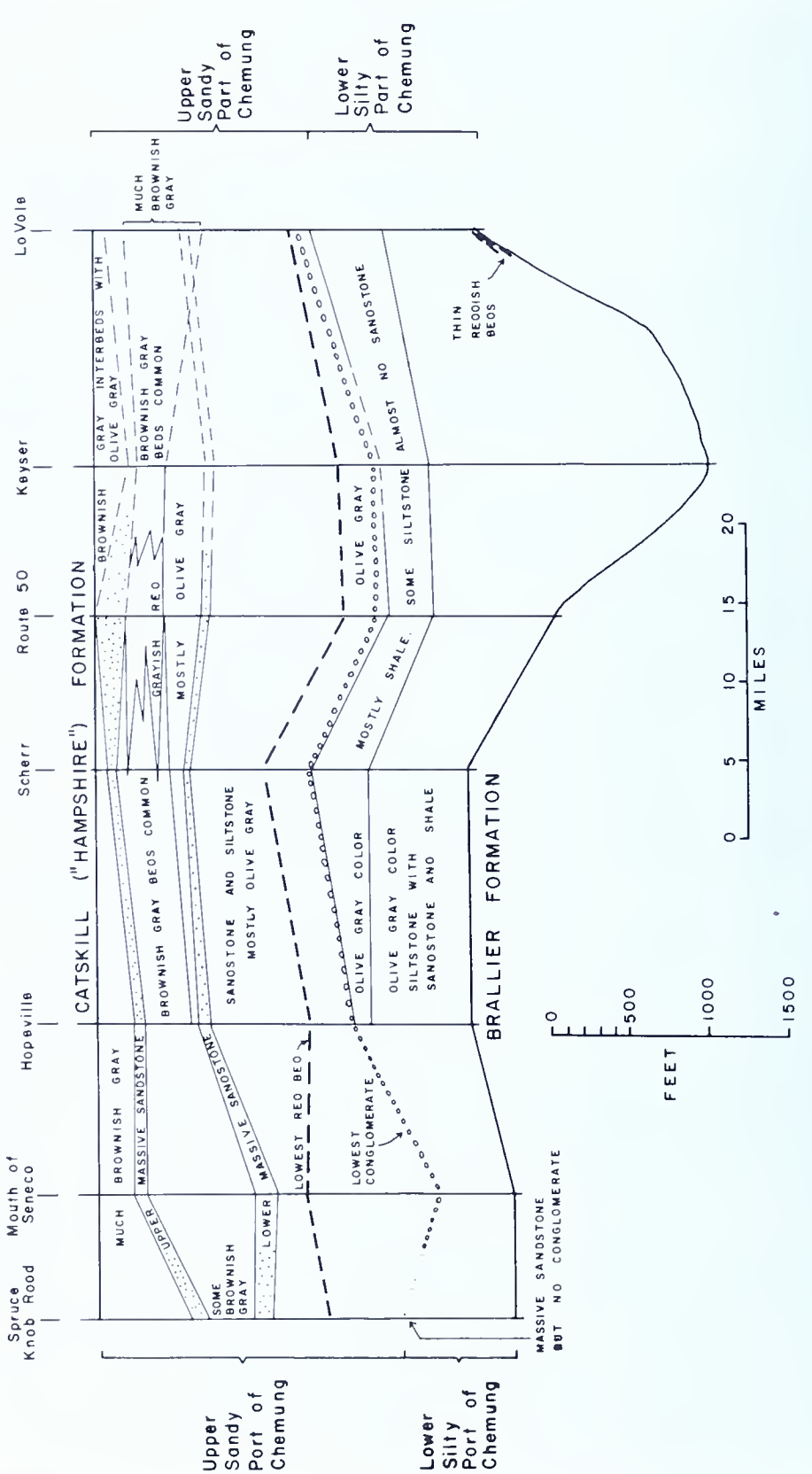

Figure 4. Details of Chemung Formation along Allegheny Front.

fossils are absent; apparently, a temporary change to terrestrial sedimentation occurred there in late Chemung time, then the sea returned briefly before the deposition of the main mass of terrestrial sediments of the Catskill Formation. Northeast and southwest of Route 50 this interval contains brownish-gray sandstone and siltstone with some marine fossils interbedded with light-olive-gray-weathering sandstone, siltstone, and shale. The reddish color diminishes both north and south of Route 50.

In most sections brownish-gray and olive-gray sandstone and siltstone are found between the upper massive sandstone and the base of the Catskill Formation. The top of the Chemung Formation is probably approximately contemporaneous throughout the area investigated, although it might be a little younger at Spruce Knob than elsewhere.

The thickness of 1670 feet of Chemung at Corriganville is based on Prosser and Swartz (1913); this value is anomalously small.

These rather persistent zones in the Chemung probably result chiefly from events in the source area from which the sediments came. Regional facies changes also occur in the formation. First, the average grain size of the Chemung decreases southwestward, apparently a result of increasing distance from the source area. This trend of decreasing grain size continues southwestward to an unmeasured exposure at Dry Run (Figure 1). Conglomeratic beds decrease in number and thickness southwestward. At Spruce Knob road conglomeratic sandstones are restricted to above the base of the lower massive sandstone unit of the Chemung. In southern Bedford County, Pennsylvania, there are Chemung conglomerates over 20 feet thick, far more conspicuous, thicker, and coarser than any individual beds at Corriganville or southward. Furthermore, the abundance and thickness of sandstone beds in the Chemung decreases southward as siltstone and shale become more conspicuous.

Beneath the lower massive sandstone unit the red beds become less abundant in number and less brilliant in color toward the southwest. Facies changes in the red beds between the upper and lower massive sandstone units in the Chemung already have been considered.

The Chemung strata were deposited in a subsiding basin which gradually became filled above sea level and then received terrestrial sediments of the Catskill Formation. The thickest Chemung in the region is at Keyser, where most subdivisions of the formation (Figure 4) are individually thicker than in other sections. Subsidence apparently was more rapid there than elsewhere, as evidenced by considerably more prominent turbidity current markings than in other sections.

Catskill ("Hampshire") Formation

This red bed sequence has been called both Catskill and Hampshire Formations. Woodward (1943, p. 497) preferred the designation Hamp-

shire Formation, but more recently the West Virginia Geological Survey has used the name Catskill Formation, because it has gained continued acceptance in Pennsylvania and Maryland.

The Catskill Formation consists almost entirely of grayish-red to brownish-gray, micaceous, fine to very fine, quartz sandstone and grayish-red to brownish-gray, micaceous siltstone which weathers lumpy to chippy. Many of the sandstones are cross-bedded, and shale chips occur in some of them. A few greenish-gray sandstones, often containing plant fragments, occur in the Catskill. These are most common in the top half and are more abundant in the southern part of the area. The proportion of siltstone in the Catskill Formation increases toward the southwest. The thickness of the formation is shown in Figure 2. The basal contact of the Catskill Formation is marked by an abrupt upward change to nearly all red beds. The top 300–400 feet of the formation is poorly exposed. Where it can be observed this interval contains more siltstone than the rest of the formation, accounting for its uncommon exposures.

The base of yellowish-gray sandstones and siltstones of the Pocono Formation is abrupt everywhere. Only a few reddish siltstone and shale beds occur in the Pocono. Dally (1956, p. 93) considers the base of the Pocono in northern West Virginia as upper Osagian in age, and he believes that an indeterminate thickness of the upper part of the Catskill ("Hampshire") Formation is Mississippian. The present study has yielded no new information concerning the systemic boundary.

SUMMARY

The Middle and Upper Devonian strata along Allegheny Front exhibit marked facies changes. The outcrop belt cuts obliquely across the sedimentary strike, which was nearly north-south, so the rate of change is more gradual than would occur in a section perpendicular to sedimentary strike.

These beds are characterized by a series of orogenic pulses which yielded clastics from the east, gradually filling the Devonian exogeosyncline. The first pulse of mud began after Oriskany deposition, and sediment size reached a maximum late in Hamilton time. A second pulse began in early Brallier time, culminating in the sandy beds at the base of the Chemung. After a temporary lull in clastic supply, the largest orogenic pulse occurred in the source area, supplying much sand and even gravel late in Chemung time. Sediment accumulated faster than subsidence, so the exogeosyncline filled to above sea level, resulting in the thick accumulation of Catskill red beds.

Stratigraphic changes toward the southwest are dominated by a thinning of formations and time rock units and by a decrease in average grain

size of clastics. In Chemung and Catskill time fewer red beds accumulated toward the southwest away from the source area.

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Lithostratigraphy of Some Middle and Upper Devonian Rocks in the Subsurface of Southwestern Pennsylvania

ABSTRACT

Subsurface sections of well samples from the Upper and Middle Devonian in southwestern Pennsylvania can be accommodated by the stratigraphic terminology developed in the nearby surface exposures of the Valley and Ridge Province. Lithofacies trends are compatible with those previously outlined by geologists working with outcrop data. There is confirming evidence in the subsurface of southwestern Pennsylvania, beginning in Late Devonian time, of a major marine regression, the climax of which was the building of the Catskill delta.

INTRODUCTION

The intent of this paper is to discuss the lithostratigraphy of a part of the subsurface sequence that to date has received little attention in western Pennsylvania. Specifically the section under investigation is a part of the marine sequence of rocks above and below a datum which is presumed to be the Tully Limestone. The time-stratigraphic units involved are parts of the Upper and Middle Devonian Series. It is not the purpose of this paper to discuss time-stratigraphic details. Paleontological material from the subsurface in the area under investigation is almost nonexistent, and without it time relationships cannot be determined. Lithological similarity, homotaxial relationships, and prevalent geological usage all lend support to the nomenclatural assignments used herein.

The area chosen for the investigation is that spread between a number of wells (for which samples were available) in parts of eight counties in southwestern Pennsylvania. (See index maps for Figs. 1, 2, and 3). Hereafter the total region covered in this paper will be referred to as "the project area."

To the west of the Allegheny Front in southwestern Pennsylvania and in the Broad Top Synclinorium of eastern Bedford County, stratigraphic information about the Upper and Middle Devonian (as well as older rocks, of course) must come from drill samples. There is no economic significance to the rocks in either the lower part of the Upper Devonian or the upper part of the Middle Devonian, at least insofar as petroleum or

gas prospects in southwestern Pennsylvania are concerned; the sequence is simply an interval to be drilled through on the way to testing the Onondaga-Oriskany objective. For this reason little attention has been paid to understanding stratigraphic relationships. With the exception of the Tully there is little agreement on stratigraphic terminology. In some parts of the project area the Tully is missing and this compounds the stratigraphic confusion. Geologists working with the outcrops of central Pennsylvania have one set of formational names, those with a grounding in West Virginian terminology prefer others, and there are those who find the section a thick slice of "no-man's land" and use no names at all. So it is that this attempt may be justified as one in which some of the facts of stratigraphic relationships are brought to light and suggestions made for the employment of stratigraphic names are discussed.

TECHNIQUES OF CORRELATION

The word "correlation" as used herein does not imply time equivalence. The correlations shown on the accompanying illustrations and referred to in the text represent observed lithic similarities of well samples. The matching of gamma-ray log characteristics in the various wells has been an important aid in this study. But facies boundaries traced from well to well are not necessarily parallel to lines drawn by matching gamma-ray log characteristics. The transgressive and regressive nature of lithofacies is demonstrated often times by relating those gamma-ray correlations which seem to parallel planes of contemporaneity to the lines joining intervals of lithologic similarity. Only a few gamma-ray correlation lines are shown on the accompanying illustrations—and those with dashed lines.

STRATIGRAPHY

Middle Devonian Series

Onondaga Group

The horizon at the top of the Onondaga Group is the arbitrarily chosen base of the section in all of the wells studied in this project. This horizon is defined (for the purpose of this study) as the top of the limestone sequence which is referred to as the "Onondaga" by most workers in the region; if a specific name is needed the limestone may be referred to as the Selinsgrove Limestone, a name better known in central Pennsylvania. Basinward (to the east of the project area) there may be some argument about which limestone is the Onondaga limestone, for a number of thin ones make their appearance in that direction and, in addition, that part of the section becomes more shaly. The dark shales of the basal Hamilton

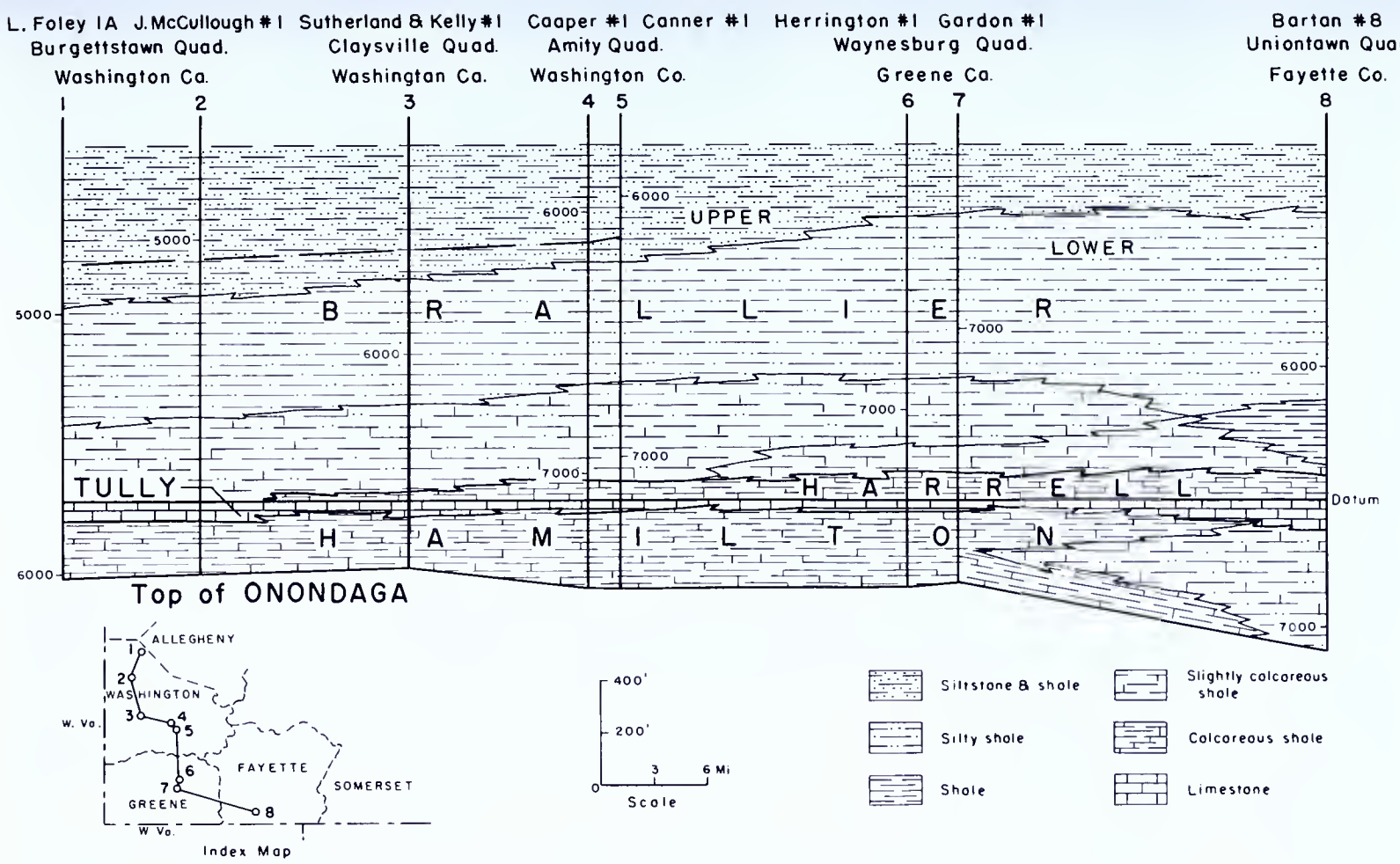

Figure 1. Lithostratigraphy of part of the Middle & Upper Devonian in SW Penna.

in that basinward direction, however, are generally quite distinct from the dark-gray limey shale facies (Needmore) of the Onondaga, thus providing an applicable criterion for separating the Hamilton from the Onondaga where the two shales are contiguous.

Hamilton Group

The rocks here assigned to the Hamilton Group offer more variety than any of the others studied. The Hamilton has been divided (Willard, 1935) in Pennsylvania into two major units, the Mahantango Formation on top and the Marcellus Formation below. This positional relationship is that of the outcrop belt, but in the subsurface of the western part of the project area the two formational units do not always coexist. A parallel situation exists in New York where, in a westward direction the Marcellus replaces rocks lithologically similar to those of the Mahantango. The two formations in the project area are found to be interfingering lithofacies units.

Marcellus Formation

The Marcellus Formation in the area under discussion embraces three main lithologies: calcareous shale which is usually medium gray in color, slightly calcareous shale which is usually dark gray, and silty to carbonaceous shale which is dark gray to black. The base of the Marcellus is the top of the Onondaga Limestone. The top of the Marcellus is either the base of the lowest Mahantango siltstone (in the eastern part of the project area) or the base of the Tully Limestone (in the western part of the area). In Figure 2, for instance, the interfingering relationship of the Mahantango and the Marcellus may be seen. In Figure 1, on the other hand, no Mahantango is present in the total Hamilton; all of the Hamilton consists of rocks of Marcellus lithology.

The Marcellus grades, in an eastward direction, from calcareous shale to slightly calcareous shale and then to dark silty or carbonaceous shale in the eastern part of the project area; thinning of the unit (from the top down) occurs in the same direction. Relatively thin (up to 45 feet, but averaging about 10 feet), limestone units make their appearance in the basal Marcellus in the eastern part of the area. One of these was informally named the "Purcell Limestone" (see Figs. 2 and 3) when it became a useful subsurface marker in the wells drilled in the Clearville quadrangle, Bedford County. A number of similar, relatively thin, limestones are reported from elsewhere in the central part of the Appalachian Basin—examples are the Cherry Valley and the Union Springs limestones of New York. The blackest, most fissile shales of the Marcellus are usually found below and just above the Purcell Limestone; these rocks

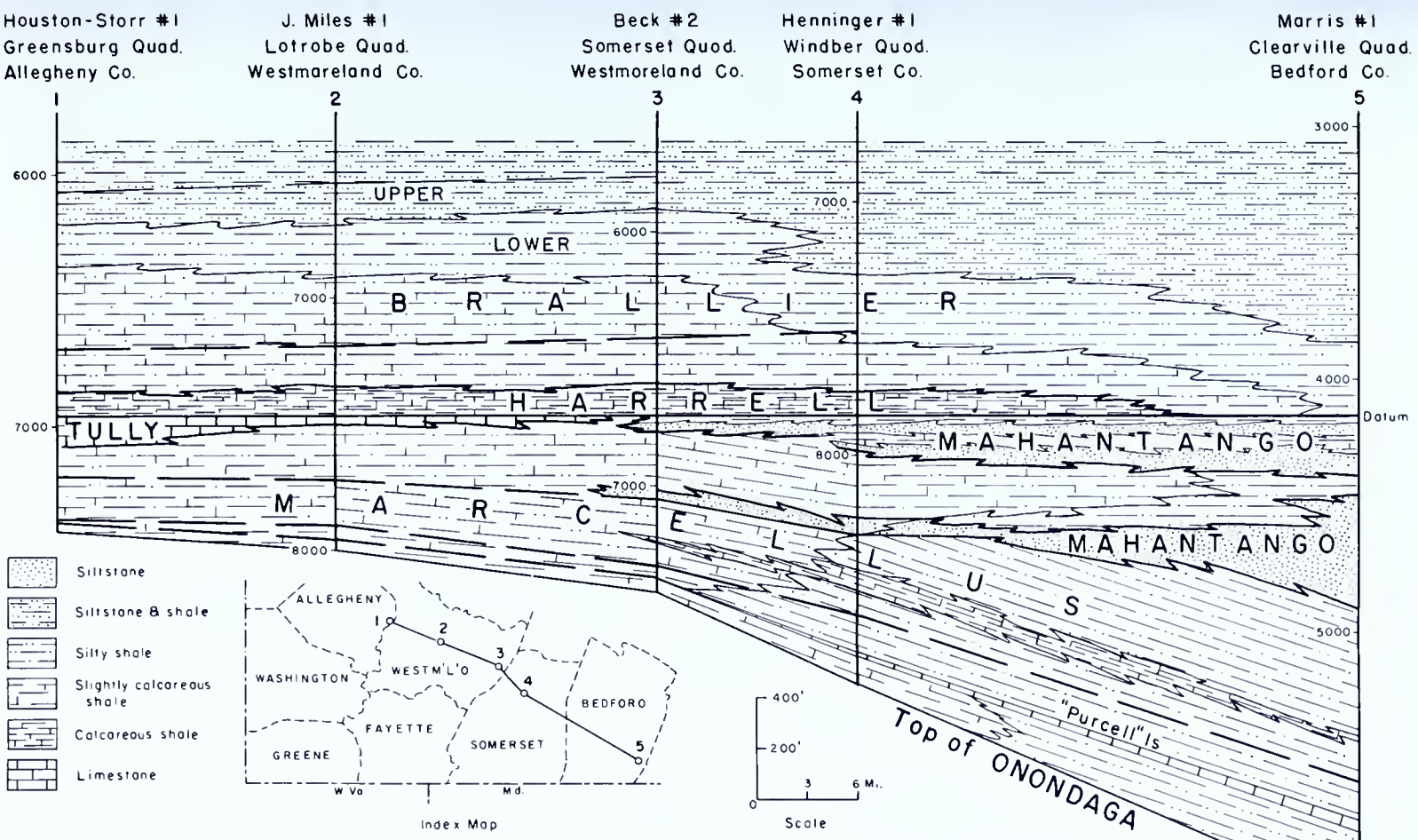

Figure 2. Lithostratigraphy of part of the Middle & Upper Devonian in SW Penna.

are quite distinctive and typify what many geologists regard as Marcellus lithology.

Where the Hamilton is thinnest in the project area (i.e., in the western part—see Fig. 1) the Marcellus is quite calcareous and shaly and, as previously mentioned, comprises the total Hamilton. Where the Hamilton is thickest in the project area (in the eastern part—see Fig. 2) the Marcellus comprises not much more than half of the Hamilton, for the wedges of overlying coarser clastics (assigned to the Mahantango Formation) thicken eastward.

Notable in the middle of the Marcellus in a part of the project area (see Figs. 2 and 3), where the bulk of the formation is slightly calcareous or not at all calcareous, is a lenticular zone, 75 feet thick or less, of quite calcareous shale.

To the northeast of the project area in the outcrops of the Valley and Ridge Province, recent work (Miller, 1961 and Conlin and Hoskins, 1962) has shown a tripartite division of the Marcellus. There a sandstone (which is not present in the area covered by this paper) is intercalated between two shales—i.e. the Turkey Ridge Sandstone is overlain by the dark and silty Mahanoy Shale and underlain by the persistent black and carbonaceous Shamokin Shale. These three units, there comprising the total Marcellus, are roughly correlative to only the lowest 300–400 feet of Marcellus in the project area.

The Marcellus is thicker in the project area than is reported from surface measurements nearby. This results because the upper boundary in the project area is considered to be the base of the lowest recognizable and persistent siltstone unit, thus embracing what is probably Willard's (1939, p. 191) "lower shale member" of the Mahantango. Inasmuch as it is demonstrable that intertonguing lithofacies units are common in the Hamilton in the eastern part of the project area it is desirable to place formational breaks at sharp lithic boundaries. Therefore, were it to become apparent that there is a coarse clastic (siltstone or sandstone), such as the aforementioned Turkey Ridge, occurring stratigraphically lower than any shown, it would be the author's recommendation that it too be included in the Mahantango Formation, thus further lowering the Marcellus-Mahantango boundary. This recommendation is clearly in conflict with outcrop terminology. Dimensions of stratigraphic investigation in this region have been increased with the addition of subsurface information and our definitions should be flexible enough to be applied to this new dimension.

It should be pointed out, in passing, that nowhere in the project area were any sandstones seen in the Hamilton; the coarsest material is a siltstone. However, not far east of the project area the "sourceward" ex-

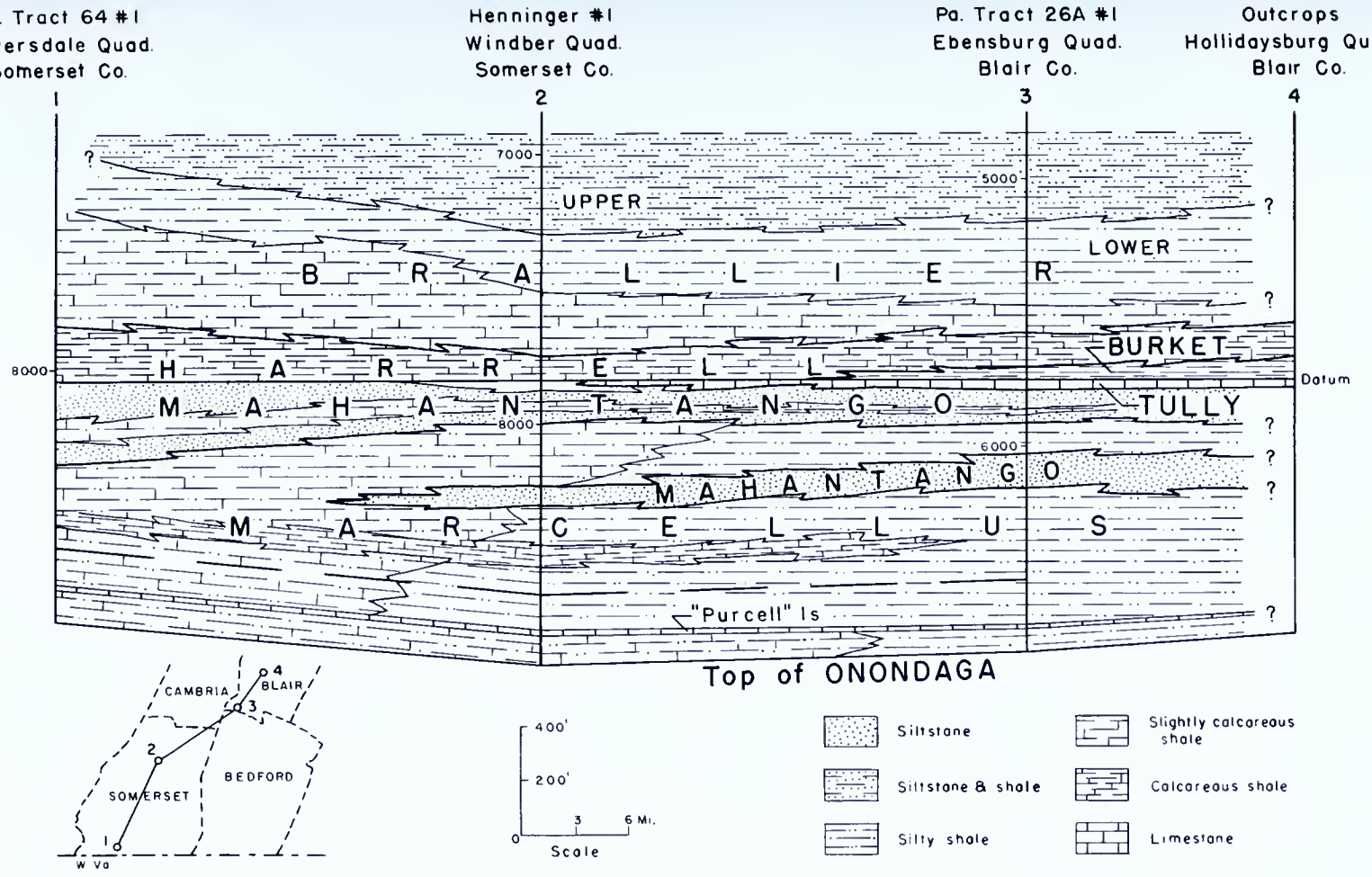

Figure 3. Lithostrotigrophy of port of the Middle & Upper Devonion in SW Penna.

tensions of these siltstone bodies are presumed to be sandstones and even conglomerates.

The thickness of the Marcellus as herein defined varies from about 220 feet in the west to 1175 feet in the east.

Mahantango Formation

The Mahantango includes all those clastics of the Hamilton Group which are coarser than shale. In the eastern part of the project area, as was mentioned earlier, the Mahantango interfingers with the Marcellus. In the western part, however, the Mahantango lithology is missing and the total Hamilton consists of rocks assigned to the Marcellus (see Figs. 1 and 2).

In the subsurface of neighboring Garrett County, Md., Amsden (1954) has used the term Hamilton to refer to what is here being called Mahantango.

The lithology of the Mahantango in the project area is that of a siltstone, light to medium gray, calcareous in some places, with some interbeds of silty, medium-gray shale.

The Mahantango is overlain by the Tully limestone where that unit is present. Where there is no Tully the top of the formation is placed just a few feet above the highest persistent siltstone and at the base of either the highly calcareous Harrell Formation or a slightly calcareous or silty facies of the Brallier Formation (see Figs. 2 and 3). The base of the Mahantango is coincident with the top of the interfingering Marcellus, as previously described.

The siltstone tongues of the Mahantango thicken to the east and, as mentioned earlier, are presumed to become coarser in that direction. To the east of the project area names have been assigned to some of these clastic wedges. One such is the Montebello Sandstone, which may be stratally continuous with the lowest siltstone shown in Figures 2 and 3. In the wells drilled in the Clearville quadrangle, operators have noted and recently named a "sandstone" at the very top of the Mahantango, calling it the "Chaneysville Sandstone." This is not the Chaneysville Sandstone first named and noted by Willard (1939, p. 191) because the sandstone of Willard occurs at least 340 feet below the top of the Mahantango and is probably the clastic unit referred to just above as the lowest one shown in the illustrations for this paper. This misnaming of the subsurface unit is an error which is likely to cause confusion. It is this author's suggestion that this error be recognized, that it no longer be promulgated, and that the "Rule of Precedence" be invoked so that hereafter the uppermost siltstone in the Mahantango, heretofore incorrectly called "Chaneysville," be called by a new name—e.g., Clearville.

In the same area (Clearville quadrangle) and just below the siltstone referred to above is another siltstone unit about 90 feet thick, which may contain limey streaks referred to by drillers as "the oolitic limestone," a limey marker bed.

Upper Devonian Series

Tully Formation

The Tully Formation has long been recognized as an important subsurface marker for drillers of "deep" wells to the Oriskany in almost every part of Pennsylvania. It is, generally speaking, a reference datum from which, once defined, subsurface geologists can begin to reckon "up" or "down" to stratigraphic units of interest. The type locality is in New York and correlation by stratal continuity is always difficult (if not impossible) to prove. But the name "Tully" should be applied in the subsurface of southwestern Pennsylvania, albeit without proof positive of its correlation with the type section, because such a decision represents the best judgement of subsurface geologists and paleontologists who have studied the fauna of nearby outcrops.

The Tully is now considered to be the lowest formation in the Upper Devonian Series in this region. Willard (1939) called it the lowest member of the two-member Rush Formation and believed it should be at the top of the Middle Devonian.

The limestone is argillaceous and fossiliferous and nowhere in the area does it appear as a crystalline high-calcium limestone. It is best developed in the area as a distinct and appreciably thick lithic unit along the Chestnut Ridge and Laurel Hill anticlinal trends in southern and easternmost Fayette County (see #8 in Fig. 1). To the south and east it becomes more shaly, to the west and north it becomes more limey and less argillaceous.

The Tully varies in thickness in the project area—from 0 to 118 feet. It may be present in some areas as a 5-foot bed; samples do not always confirm the presence of so thin a bed. Gamma-ray logs sometimes indicate its presence where its presence is not otherwise noted. The Tully is of either minimal thickness or absent in southern Somerset and Bedford Counties.

The Tully is bounded on the bottom by either calcareous or slightly calcareous shale of the Marcellus, or by a thin (10 feet or less) argillaceous and slightly silty bed at the top of the Mahantango. The Tully and the Marcellus seem to grade imperceptibly into each other. The top of the Tully in places seems to be disconformable with overlying rocks; well sections at both ends of the section in Figure 3 illustrate the divergence of beds at the boundary between the Tully Limestone and over-

lying beds. The overlying beds are assigned to the Harrell or Burket Formations over most of the project area. But in the southeastern part of the area (Clearville quadrangle) it is the lithology of the Brallier Formation which overlies the very thin and almost nonexistent Tully, or overlies the Mahantango in the instances where the Tully is absent. Referring once again to the apparent unconformable relationships of beds at the top of the Tully, Cooper and Williams (1935) noted this in New York, as did Willard (1939) in Pennsylvania, and Woodward (1943) in West Virginia. An unconformable relationship between the Tully and the older underlying formations has been noted by others but such a relationship is not apparent in the project area.

Burket Formation

The Burket Formation is recognizable in only one of the well sections studied (#3 in Fig. 3). Butts (1918) first named the Burket, a carbonaceous, black, noncalcareous, and fissile shale and described it at its type locality a few miles south of Altoona. It lies just above the previously mentioned unconformity at the top of the Tully and this may explain why its presence or absence was surprising and unpredictable to some of the geologists first studying this part of the section.

The Burket is much less calcareous, if calcareous at all, than the overlying Harrell. Where observed in the project area the Burket is underlain by the Tully with a contrasting argillaceous limestone lithology. Willard (1939) placed the Burket at the top of the Rush Formation.

The Burket is 45 feet thick in the only well section in which it was found. The Burket has been reported to the north and east in outcrop sections in Pennsylvania, but it is not believed to extend south of Pennsylvania (Willard, 1939, p. 219).

Harrell Formation

The Harrell is a dark-gray to nearly black shale which is quite calcareous—so limey, in fact, that in some places it has been mistakenly identified as the Tully where the Tully was absent.

The type locality of the Harrell is a few miles east of Hollidaysburg. Willard (1939) gave the Harrell the status of a "member" at the base of his Fort Littleton Formation.

Like the Burket and the Tully, the Harrell is not continuous throughout the area studied (see Figs. 1 and 2). In most places it overlies the Tully, but elsewhere it is underlain by the Burket or the Mahantango. Its thickness is more constant than most of the other units investigated, ranging from 0 to 220 feet and averaging about 90 feet thick. The Harrell is recognized in Maryland and West Virginia and is widespread in the exposures to the northeast of the project area.

Brallier Formation

The Brallier is the thickest of the units studied. Its upper boundary, however, is not a part of this study, but others, such as Swartz (1946) and Willard (1939) have estimated it to be from 1500 to 2000 feet thick. It is overlain by the Chemung Formation in the area studied.

The Brallier has been divided here informally into two units—an upper and a lower member. The Lower Brallier was studied in its entirety, but only the lower part of the Upper Brallier was examined.

The Lower Brallier overlies the calcareous shale of the Harrell in most places, but it is also in contact with the Tully and Mahantango Formations (see figures). The Lower Brallier is made up of two lithofacies—a slightly calcareous gray shale facies overlain by a silty olive-green to gray shale facies. It is from 0 to 450 feet thick in the project area.

The Upper Brallier is the thicker of the two members. Its boundary with the Lower Brallier is gradational. The Lithology of the Upper Brallier is one of alternating siltstones and silty shales, the base occurring at the last definable siltstone unit. The top boundary of the member has not been carefully defined here but the member is presumed to be a rather homogeneous unit with coarser clastics increasing as one goes higher in the section.

The parallelism of lithofacies boundaries both within the Brallier Formation and at the top of the Harrell are well illustrated in Figure 2. In that diagram is illustrated a cross-sectional view of the results of part of the marine regression during the Late Devonian epoch, a regression typified by coarse clastics succeeding finer clastics and which was to culminate later in the building of the great Catskill delta.

CONCLUSIONS

Some amendments and stretching of prior stratigraphic definitions are suggested herein but without, it is to be hoped, permanently straining the original intent of these definitions. The test of useful stratigraphic terminology—such as formational names—is their applicability. This paper has been an effort to apply preexisting terminology to a small segment of the subsurface without inventing more labels where older and well-established ones would do, even though they at first seemed inadequate.

The evidence here presented, though restricted vertically and laterally, seems to be in accord with previously published geological and paleogeographic concepts of the Upper and Middle Devonian rocks. A number of excellent contributions to our understanding of surface exposure of Devonian rocks have been written but little has been done to relate that information to the data now becoming available from the subsurface. This paper has been an attempt to accomplish something of that sort.

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The Correlation of Upper Devonian Chemung Sands in West Central Pennsylvania, North of Pittsburgh

ABSTRACT

The correlation of the various producing sands of Upper Devonian-Chemung Age in Western Pennsylvania is problematical. For many years, until very recently, most of the correlating was done by the cable tool driller. This has resulted in the use of a single name over a large area and, consequently, for several sands which are not the same as in the type locality. A correlation chart is presented to show the various sands that have been and are now identified by these names.

It is not proposed that the names as herein presented are historically correct, but they are well identified by the drillers and operators in a given area.

The "2nd Bradford" sand is one of the main producing sands in Armstrong, Indiana, Jefferson and Westmoreland Counties. The producing sand is a lens that is elongated and more or less parallel to the regional strike. The thickness ranges from 0 in the west to 90+ feet in the thick central portion and to around 10 feet on the east. The longitudinal axis is 50 miles as compared to 8 miles for the transverse axis.

The characteristics of this sand lens are those of an offshore bar. The name Armstrong Bar is proposed for this feature.

INTRODUCTION

It is the purpose of this paper to (1) show that the Upper Devonian sands in Pennsylvania can be correlated into zones by sample analysis and by the use of Gamma Logs, (2) illustrate the need for a state wide study and correlation of these sands which have produced gas and oil for the past 70 odd years and still hold promise for future development, and (3) show the development of an offshore bar in the Bradford zone.

When the writer first began work in this area some 13 years ago, the only subsurface geological records available were "drillers' logs." Since these commonly produced more questions than answers, the writer undertook a project of examining samples from all available wells. At the present time there are about 300 detailed sample descriptions in the files. These were used for correlating the drillers' logs according to a system developed by J. French Robinson (1930) and published by the Engineers' Society of Western Pennsylvania under the title of "Stratigraphy of Southwestern Pennsylvania."

Figure 1 shows the relationship between correlations in this report to those of John Bergsten (1958, 1959, 1960), formerly of the Pennsylvania Survey. The writer has added the Armstrong County section to Figure 1.

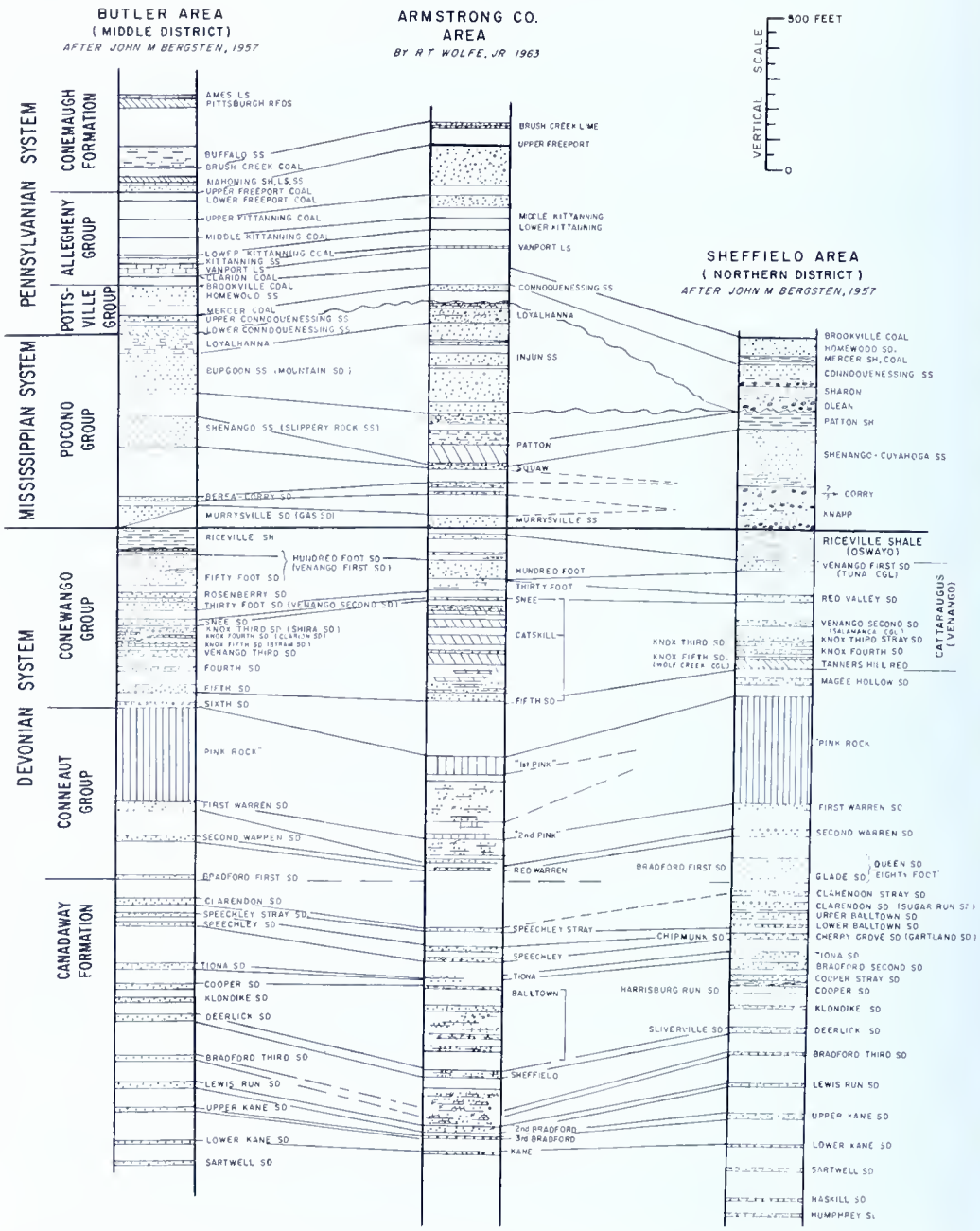

Figure 1. Calumnar sectians showing stratigraphic positians af ail and gas sands af western Pennsylvania.

The Upper Devonian in this area consists of about 5,500 feet of interbedded shales, sands, and siltstones with the base being an argillaceous lime—the Tully.

The upper 2,000 feet of the section contains most of the oil and gas producing sands in western Pennsylvania. Parke Dickey (1941, 1943, 1946), R. E. Sherrill and L. S. Matteson (1943, 1945) have done an excellent job in depicting the correlation of the "Venango" group in the

Oil City-Franklin-Titusville region (1941, 1943, 1945, 1946). William S. Lytle and John Bergsten have published correlations in the Butler and Foxburg quadrangles (1955, 1961).

This paper deals with the correlation of those sands ranging from the Speechley Stray to the 3rd Bradford as shown in the Armstrong area section of Figure 1. These sands occupy approximately 700 feet of section of which 25 to 50 per cent is very coarse silt to coarse sand; i.e., having a grain size from 1/32 mm. to 1 mm. The correlation chart (Figure 1) shows these sands to be in the Canadaway Formation of Chadwick (1935), which is correlative to the Chemung of Maryland and West Virginia.

CROSS SECTIONS

The sections included in this report traverse an area of approximately 1,800 square miles in Clarion, Jefferson, Armstrong, Indiana, and Westmoreland Counties, Pennsylvania. The area under consideration and the section lines are shown in Figure 2.

Gamma logs were used in these sections in preference to sample logs because of (1) their adaptability to scale reduction and (2) the availability of more gamma logs than sample logs. The gamma log's ability to give characteristic shale "kicks" makes it a very good correlation tool; for example, the gamma ray marker used as a datum on the cross sections cannot be identified in the samples.

Cross section A-A′ (Figure 3) is a N.E.-S.W. section which is essentially parallel to the regional strike. The remaining sections B-B′ to F-F′ (Figures 4 to 9) were constructed nearly perpendicular to strike. These cross sections illustrate that the formations; i.e., Speechley, Tiona, etc., can be correlated over a relatively large area, but the individual sand units that compose these formations are quite lenticular and cannot be correlated with any degree of certainty for more than a few miles and in some instances only a few thousand feet.

Section A-A′ (Figure 3) was prepared to emphasize the individuality of the various sand units comprising each formation and to show the development of the Bradford sand. The Balltown sand lens from Well 897 to 772 is gas bearing.

The following table correlates the wells common to the various East-West cross sections and the N.E.-S.W. cross section A-A′ (Figure 3):

Well No. on A-A′	*Common to Section*
F-9231	B-B′
778	C-C′
F-6714	D-D′
897	E-E′
F-6768	F-F′
528	G-G′

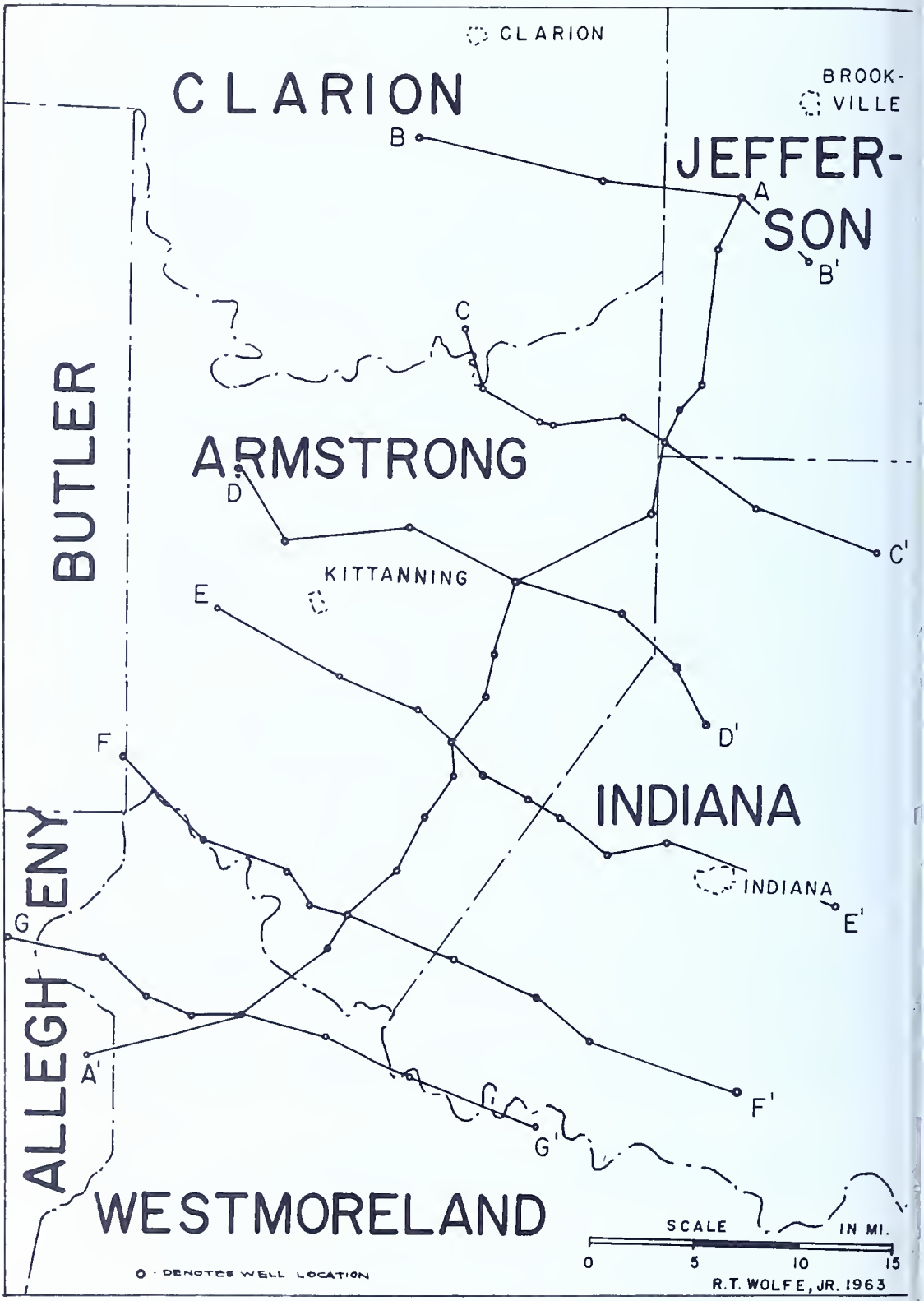

Figure 2. Index map showing location of cross sections.

The cross sections in general are quite similar, but they vary greatly when one considers the detail. Therefore, a description of the individual cross sections will be deferred and left to the reader's observation. The similarity of the cross sections is due primarily to the uniformity of the gross formational thickness. As an illustration, isopach maps were made using 143 sample logs from the Murrysville sand (base of the Mississippian), the top of the Catskill red beds and from the top of the Speechley to the 2nd Bradford as herein defined. The following intervals were found to be consistent:

Interval from Murrysville to top 2nd Bradford	2,025′
Interval from Catskill to top 2nd Bradford	1,650′
Interval from Speechley to top 2nd Bradford	575′

The consistency of these intervals indicates this area does not reflect the regional thinning to the north. A hinge line is postulated south of Kane. However, much work needs to be done in this area.

DESCRIPTION OF SANDS

The SPEECHLEY STRAY is usually composed of very coarse light-green-grey silt to very fine sand. In a few localities it may be composed of very fine white sand and be as thick as 25 to 30 feet. It is gas bearing in very few wells.

The SPEECHLEY is usually composed of three sand units but has persistently only one unit in the western area near the Butler County line. As many as seven distinct sand units have been identified in the Speechley interval identified on the gamma logs.

The Speechley sand is lithologically heterogeneous varying from a brownish silt to very coarse sand with red cementing material. The most persistent characteristics of the Speechley are (1) its presence over a large area and (2) the variability of individual units.

Paradoxically, it is not the "best looking" sand that produces the gas but rather the finer grained, light-to dark-brown sands and coarse silts. The Speechley also produces some oil in this area.

The TIONA sands are not very important as gas reservoir rocks in this area. They usually consist of dark-brown siltstone in the samples. However, locally there may be a very fine to fine sand developed with a thickness of 15 to 20 feet in which a fair gas well may be obtained by fracturing. A small field of this type has been developed in Wayne Township, Armstrong County—about the position of the "G" in Armstrong on the index map (Figure 2).

The BALLTOWN sands are quite similar to the Tiona in development. The upper most unit (referred to as 1st Balltown by the driller) is the most persistent. A gas pool has been developed in this unit just east of the

Borough of Elderton along the Armstrong-Indiana County line. Wells F-6121 and F-12198 of Section E-E′ (Figure 7) are in the pool.

A description of the Balltown sand from one of the wells in this pool follows:

Depth of Sample	*Description*
2784–2790	Grey shale 75%, dark-brown silt 25% (Top Balltown sand—2786′)
2790–2796	Very coarse brown silt 50%, grey silt 25% shale 25%—gas @ 2795′—46,000
2796–2802	Very fine brown sand
2802–2808	Very fine brown sand
2808–2814	Very fine brown sand 75%, grey shale 25% Gas @ 2806′—48,700
2814–2820	Grey shale 20%, very fine brown sand 80%
2820–2826	Very fine brown sand
2826–2832	Very fine brown sand 75%, shale 25%
2832–2838	Shale 25%, very coarse brown silt 50%, very fine sand 25% (Base Balltown sand—2838′)
2838–2844	Coarse light silt 50%, grey silt 25% grey shale 25%

The SHEFFIELD sand is usually a brown siltstone horizon although in northern Armstrong and southern Clarion Counties these silts are gas bearing and respond to fracturing.

The BRADFORD sands are the most prolific gas producers and are the best developed of any of the "Chemung" sands discussed. The interval between the Sheffield and the Bradford sands is quite nondescript on the gamma log, but in the samples this interval consists of very slightly to slightly calcareous green-grey siltstone containing crinoid-stem fragments and occasional brachiopod and fusalinid fragments.

A description of the samples in the lower section between the Sheffield and Bradford sands and the Bradford sand for Pittsburgh Plate Glass Company Well No. 900 used on Section A-A′ (Figure 3) follows:

Depth of Sample	*Description*
3412–3451	Light-green-grey silt, slightly calcareous with fossil fragments
3451–3464	Light-green-grey silt with shale interbeds
3464–3472	Light-green-grey silt, slightly calcareous and fossiliferous
3472–3478	Green-grey silt 30%, shale 20%, very fine sand with few coarse sand grains 50% (Top Bradford sand—3475′)
3478–3490	Very fine, light-brown sand with few medium grains
3490–3496	Fine to medium, brown sand

Depth of Sample (Continued)	*Description (Continued)*
3496–3507	Very fine to fine sand, few coarse grains
3507–3512	Very fine, brown sand 90%, grey shale 10%
3512–3518	Grey shale 10%, very fine, light-brown sand 90%—Gas @ 3512′
3518–3525	Very fine, light-brown sand 90%, grey shale 10%
3525–3531	Grey shale 15%, very fine, light-brown sand 85%—Gas @ 3527′
3531–3537	Very fine, light-brown sand 85%, grey shale 15%
3537–3543	Grey shale 15%, very fine, light-brown to white sand 85%, some pyrite
3543–3550	Very fine, light-brown to white sand, some black residue in pores 90%, grey shale 10%
3550–3557	Grey shale 10%, very fine, light-brown sand 90%—Gas @ 3550–57′
3557–3562	Very fine, light-brown to white sand 80% grey shale 20%
3562–3568	Grey shale 40%, very fine, white sand 60%
3568–3574	Coarse white silt 20%, grey shale 80% (Base Bradford sand—3570[a])
	Total Depth—3574′. Plugged back to 3535′.
	O.F.B.F.—9,500 cu. ft.
	A.F.—1,220,000 cu. ft.
	R.P.—1195# in 50 hrs.

Mr. W. A. Waldschmidt (1957) made a petrographic analysis of several samples of Bradford sand that were recovered from a shot hole and found:

1. Quartz is "the dominant sand grain forming mineral."

2. The quartz grains are angular and range from 0.05 to 0.25 mm. with a few grains up to 0.6 mm. Many of the grains are elongated with the longitudinal axis being parallel to an indistinct bedding.

3. The accessory minerals are plagioclase, orthoclase, muscovite, biotite, dolomite, and tourmaline. The feldspar grains are quite similar to the quartz grains in shape and size but are slightly altered to sericite and kaolinite. The muscovite and biotite plates were up to 0.04 mm. in thickness and .4 mm. long with a few of the plates being slightly twisted. The dolomite was reported to be clastic, but a small amount was definitely cementing material.

An X-ray analysis of these samples showed the clay percentage to be from 6.2 to 1.7 per cent averaging 3.6 per cent for the samples investigated. The ratio of clay mica to kaolinite and chlorite was .50 and .40 with one sample being 2.20. A thin clay parting also showed a ratio of 2.40. No water sensitive clay—montmorillonite—was present (1957, Dr. J. W. Early, personal communication).

The porosity for these samples ranged from 10 to 16 per cent. Permeability determinations were not made on these samples although permeability from 2.2 to 28.5 millidarcys has been reported for the Bradford sand (service company laboratory reports).

Figure 10 is a gross isopach map of the Bradford sand. The writer believes that the distribution of the sand body and its vertical developments represent an offshore bar. This feature covers an area of approximately 200 square miles and consists of three main areas of development—(1) the northern lobe in the Brookville quadrangle, (2) the central lobe in the Smicksburg-Rural Valley quadrangles, and (3) the southern lobe in the Rural Valley, Elders Ridge and Freeport quadrangles. The latter lobe is divided into two sections by a lineament, considered to be a tidal channel which is shown on the Bradford sand isopach map by the 30-foot contour with depression hachures, located in the northern part of the Elders Ridge quadrangle.

To the west the sand body thins to zero while to the east the sand thins to 10 feet and has an irregular development. Another lineament can be seen on the isopach map (Figure 10) just south of the Indiana-Jefferson County line on the Smicksburg quadrangle. This is also shown by Well F-12237 of Section C-C′ (Figure 5).

A third area of thickening of the Bradford can be seen on Section E-E′ (Figure 7) Wells F-11600 and F-12108. These may also be bars, but not enough drilling has been done to delineate them as such. The thicker portions of the sand body are the result of a coalescing of the 2nd and 3rd Bradford sands. This is shown on Section A-A′ (Figure 3) which gives a longitudinal section through the bar. The writer proposes that this feature be given the name Armstrong Bar.

CONCLUSIONS

1. By using gamma ray logs and sample studies, the Middle Devonian sand horizons can be correlated for relatively long distances parallel to strike and with difficulty perpendicular to strike.

2. The oil and gas producing sections are primarily stratigraphic traps due to the development of offshore bars and the preservation of these bars in subsequent geologic time to serve as reservoirs.

3. With this type of approach—cross sections and the common usage of gamma ray logs—a basin wide study of the Chemung sands is feasible.

The writer wishes to thank Mr. J. W. Trenkle, Manager of the Gas Department of Pittsburgh Plate Glass Company, for permission to publish this paper, Dr. E. T. Heck for reviewing the manuscript, and the many independent operators who have furnished the writer with information through the years.

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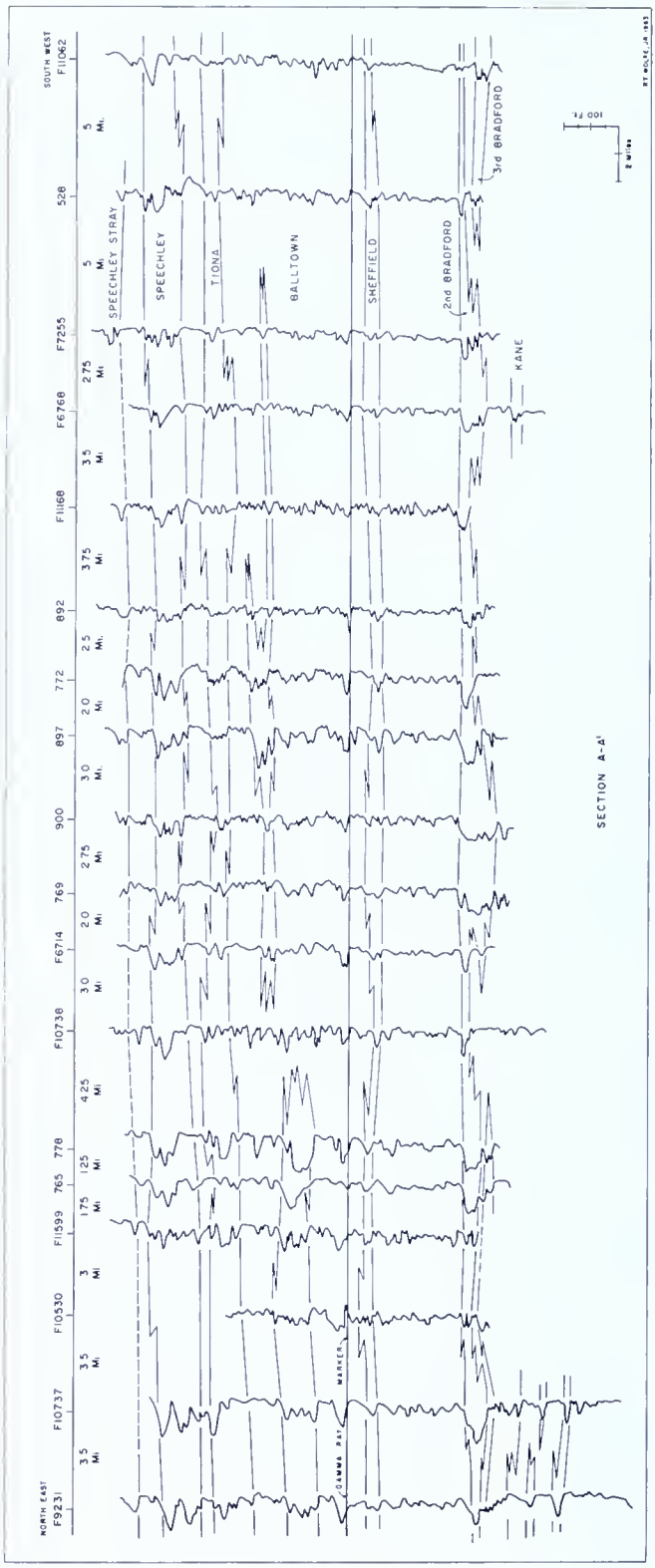

Figure 3. Cross section along line A-A'.

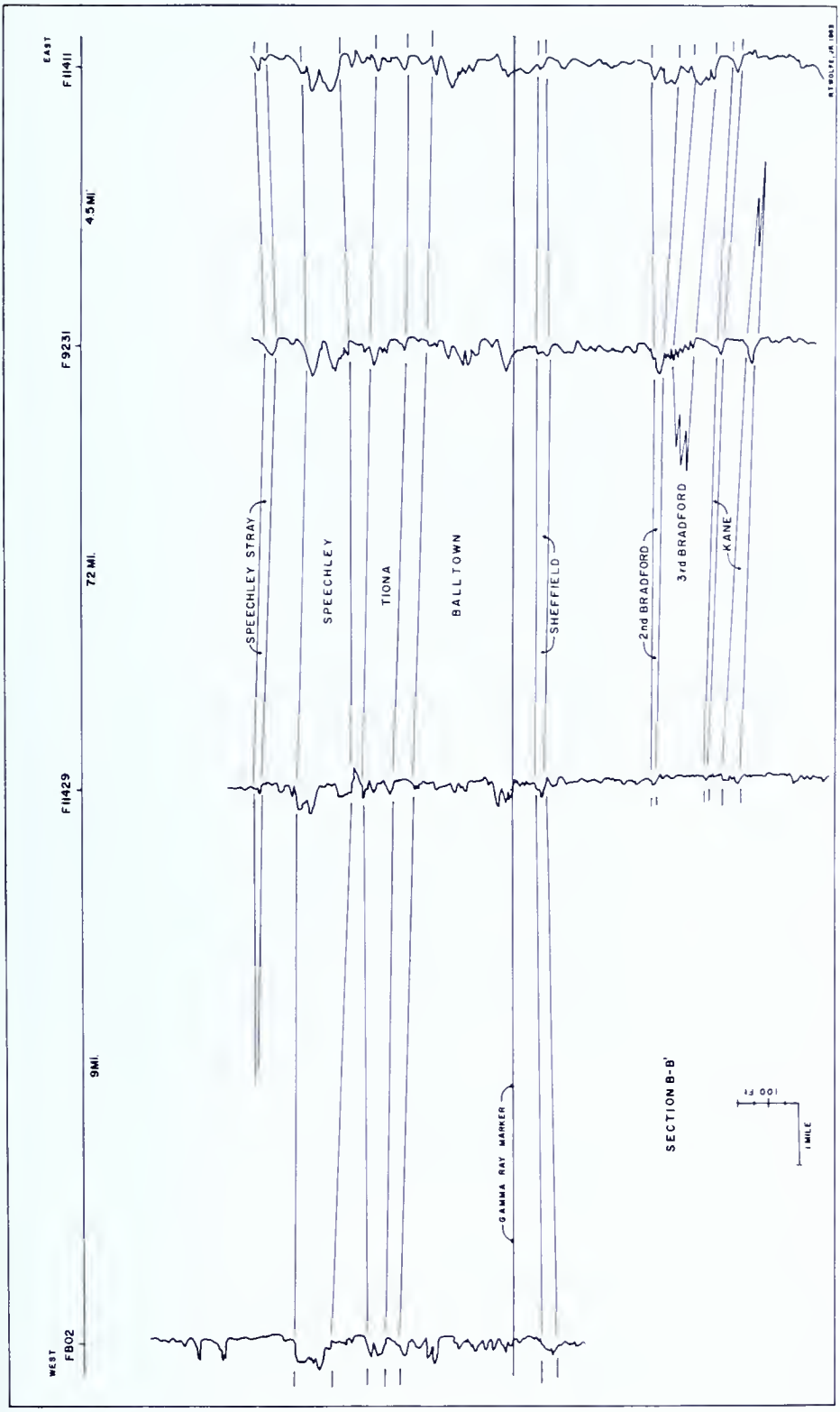

Figure 4. Cross section along line B-B'.

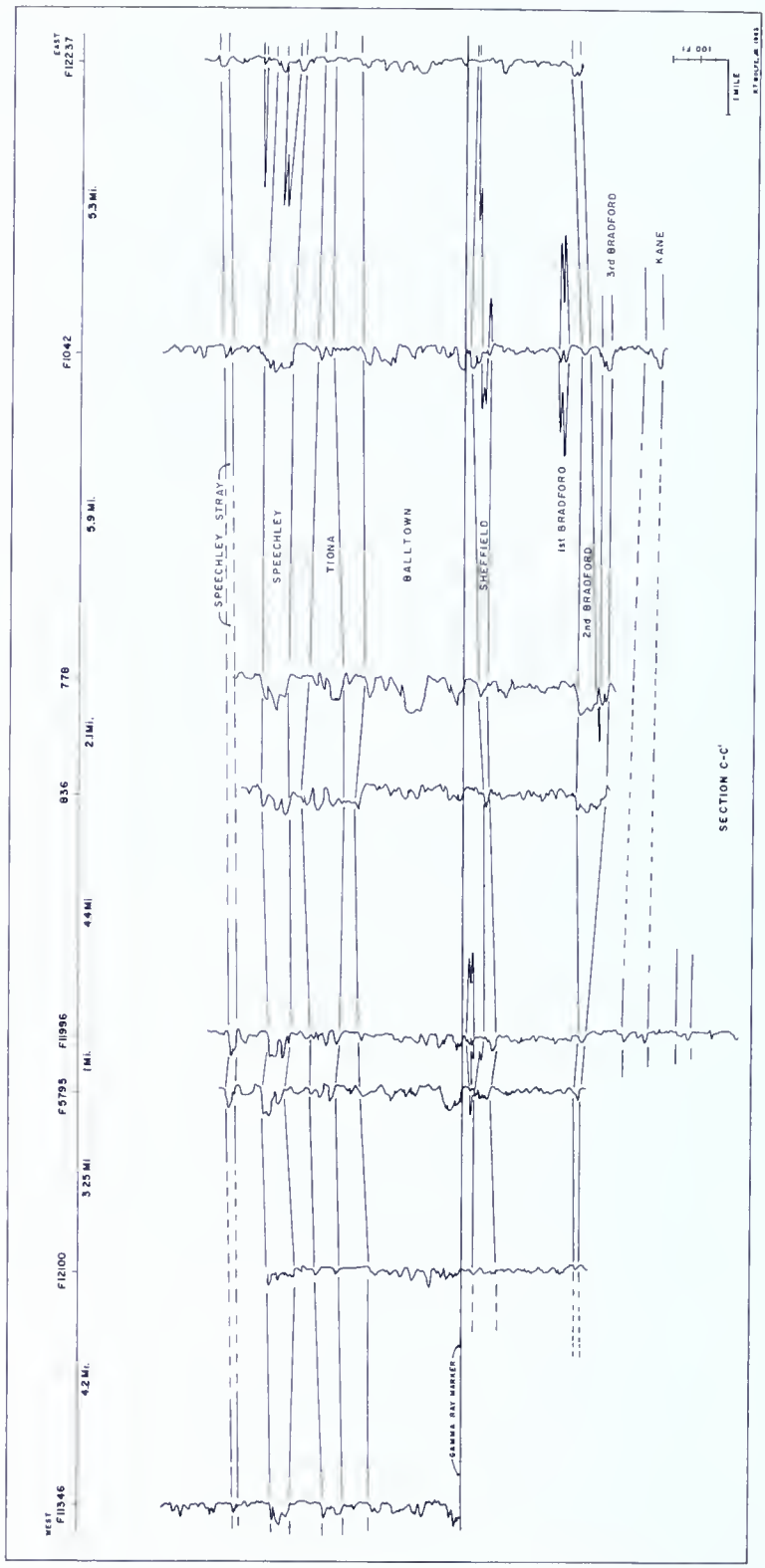

Figure 5. Cross section along line C-C'.

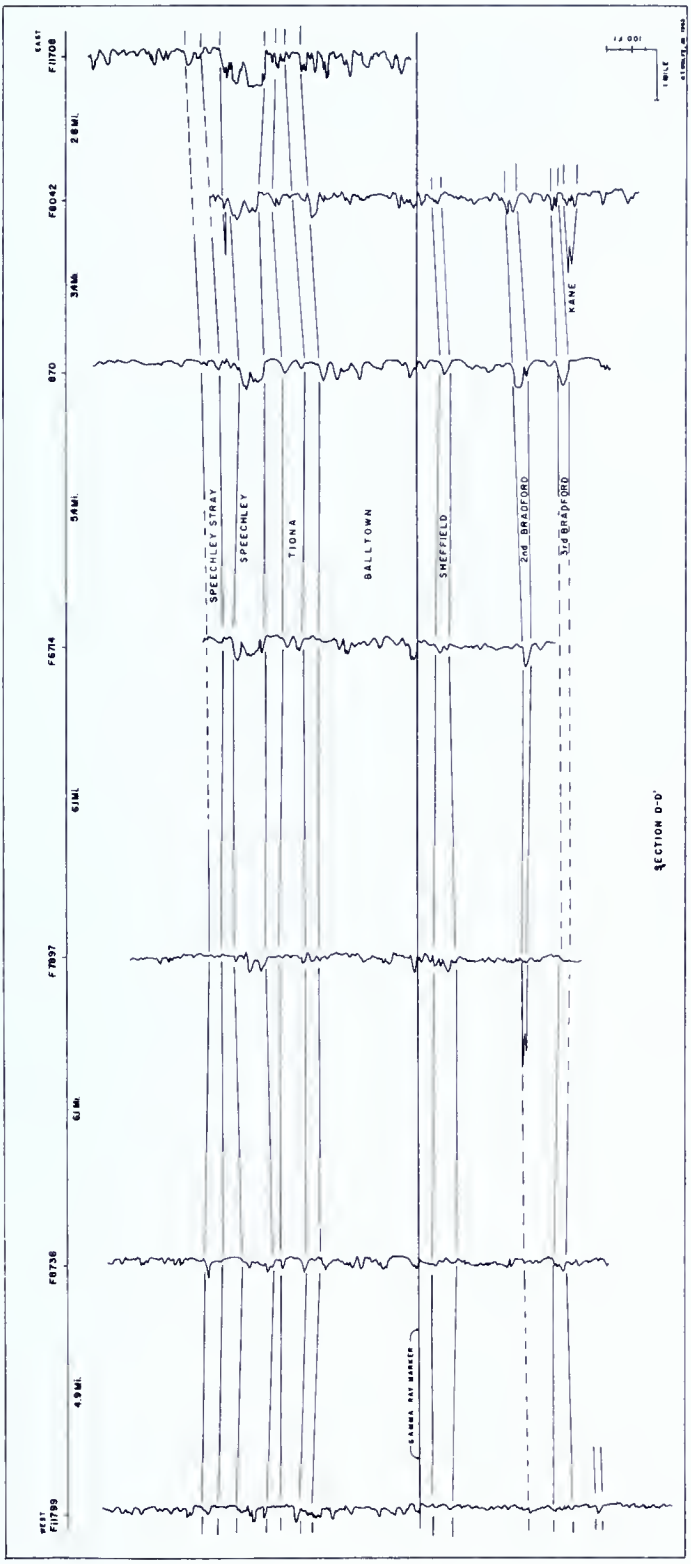

Figure 6. Cross section along line D-D'.

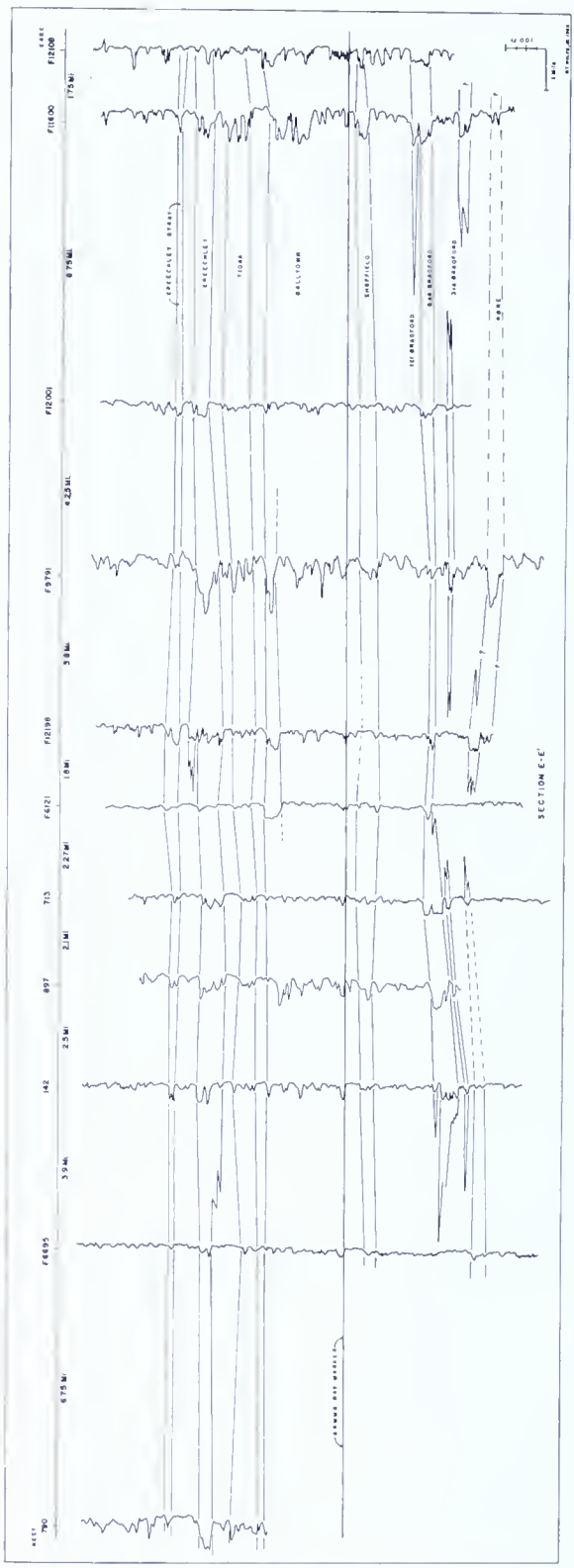

Figure 7. Cross section along line E-E'.

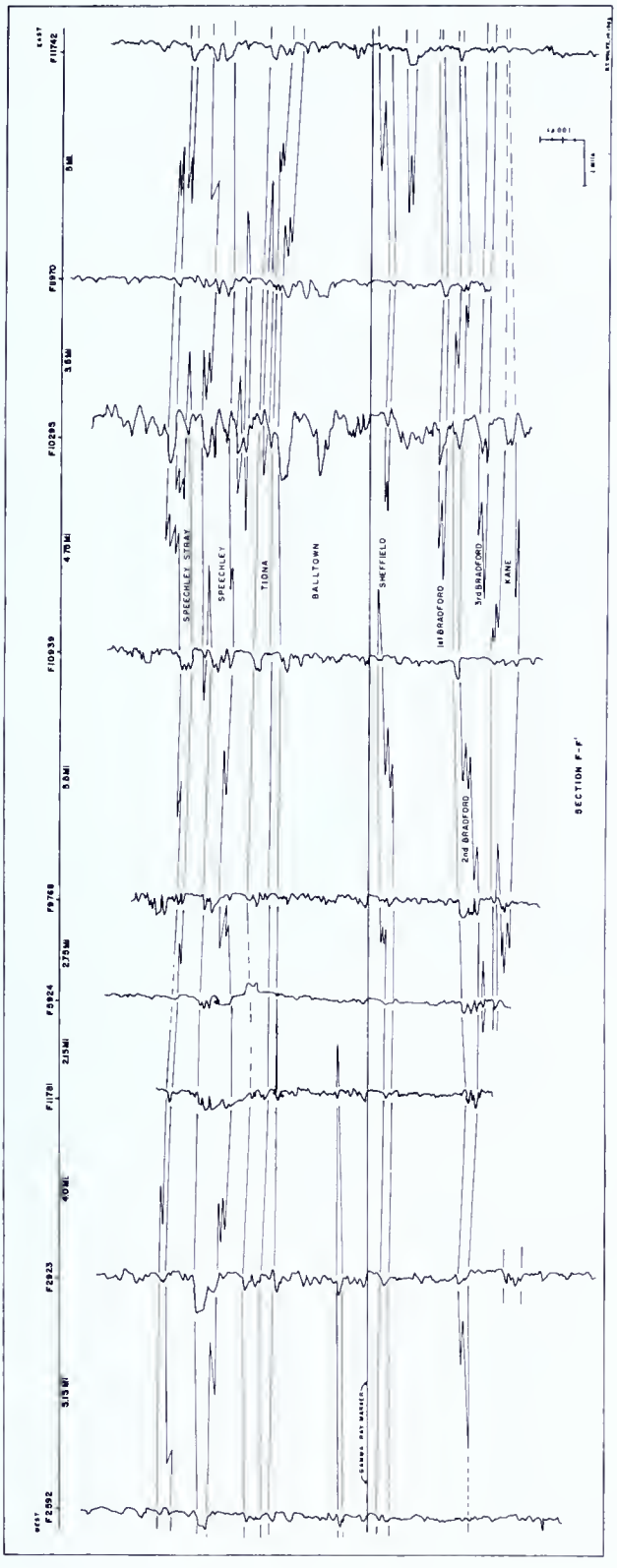

Figure 8. Cross section along line F-F'.

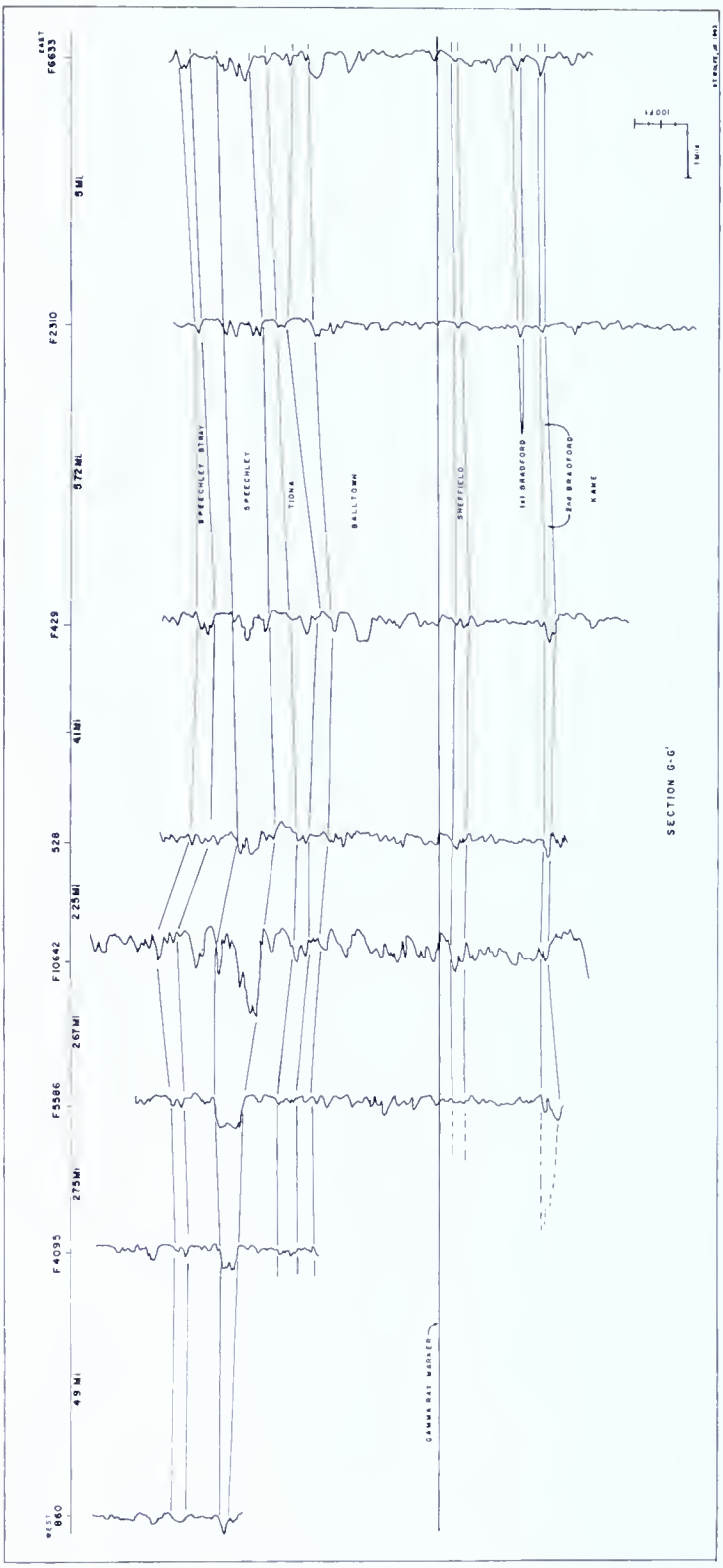

Figure 9. Cross section along line G-G'.

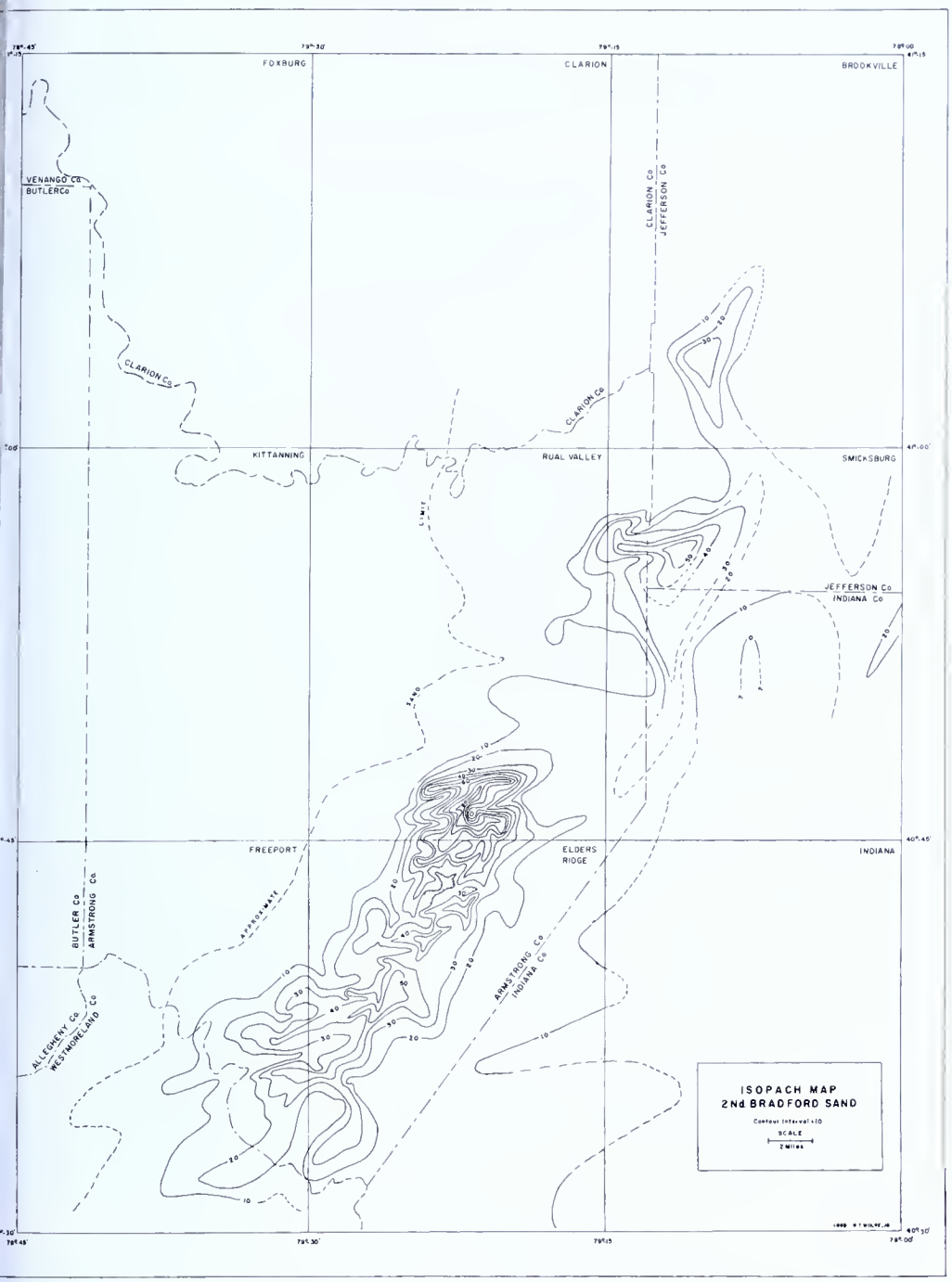

Figure 10. Isopach map of the 2nd Bradford Sand.

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A Restudy of the Chautauquan Series of Allegany County, New York

ABSTRACT

The Chautauquan Series of Allegany County, or the rocks of Upper Devonian age from the base of the Dunkirk Shale to the base of the Wolf Creek Conglomerate, is divided into time-stratigraphic, biostratigraphic, and rock-stratigraphic units. Because different criteria are used to define each type of unit, the three sets of contacts are not necessarily coincident with each other.

As here defined, the McHenry Valley Substage of the Cassadaga Stage includes beds between the base of the Alfred Station Coquinite, which occurs in the stratigraphic horizon of the Rushford Sandstone and the "Bradford Third" sand, and the top of the Cuba Formation, which is the youngest strata of the *Tylothyris* Range Zone and lies in the horizon of the "Bradford First" sand.

In addition, many of the rock-stratigraphic units of Allegany County are redefined and reclassified. Three groups are recognized in ascending order: the Canadaway and Conneaut Groups and the Supra Conneaut (informal usage). The contacts of the Conneaut Group, which transgress time-stratigraphic planes toward the west at about five feet per mile, are placed at the first and the last continuous sequence of fossiliferous strata. A projection of the Conneaut-Supra Conneaut contact to Jamestown, New York (standard section of the Conneaut) reveals that the Supra Conneaut is not present and that the Conneaut Group is unconformably overlain by the Conewango Group of Bradfordian age. Elsewhere, the Supra Conneaut includes the beds from the base of the Wellsville Formation to the base of the Wolf Creek Conglomerate. Heretofore, this succession was classified as Conneaut; lithologic and paleontologic evidence indicates that it overlies the "true" Conneaut Group.

A statistical study of 132 fossil collections suggests the presence of two biostratigraphic zones: the *Tylothyris* Range Zone and the *Cyrtospirifer* Assemblage Zone. Although the zones may be extended throughout the Chautauquan Series, it is stratigraphically sound to limit them to the confines of the Conneaut Group.

INTRODUCTION

This paper describes certain stratigraphic relationships of the Chautauquan Series of western New York, principally in Allegany and Cattaraugus Counties (Fig. 2, legend). Outcrop and well data are presented and correlations are made with the type Chautauquan section in Chautauqua County, about 45 miles west of the study area.

The stratigraphy of many of these beds, although commonly cited as integral units of the "Catskill Delta," is poorly understood east of the

type section. Except for the studies of Bradley and Pepper (1938) and Pepper and deWitt (1951), who examined the lower part of the series, and Woodruff (1942), who studied the upper part of the series, the rocks of Allegany County and adjacent areas have not been treated in detail.

The strata under investigation are divisible into (a) rock-stratigraphic, (b) biostratigraphic, and (c) time-stratigraphic units. *Each type of unit is a distinct stratigraphic entity; is governed by a very definite concept and very different criteria; and is theoretically independent of all other units.* Consequently, the contacts of one set of units may be (a) conformable or (b) disconformable to those of another set. Both relationships exist in this area.

The writer gratefully acknowledges many helpful discussions held with Helgi Johnson and H. P. Woodward of Rutgers University. He also acknowledges the generous assistance of Arthur Van Tyne of the Geological Survey of New York in obtaining the well samples used in this study.

STRATIGRAPHY

Time-Stratigraphic Units

The Chautauquan Series and the Cassadaga Stage include all the rocks from the base of the Dunkirk Shale to the base of the Panama or Wolf Creek Conglomerates (Cooper et al., 1942). In the area of study, it includes the Canadaway and Conneaut Groups and the Supra Conneaut (Fig. 1).

Although the contacts of these groups transgress time to the west, many beds within the groups extend laterally for many miles and may well approximate local time-stratigraphic horizons. Two such horizons are the Cuba Formation and the Alfred Station Coquinite (new name). Both horizons occur throughout much of western New York and northern Pennsylvania, maintain a fairly constant stratigraphic separation of about 500 feet, and are stratigraphically "intersected" by other rock units (Fig. 1). Furthermore, (a) the Cuba marks the upper limit of *Tylothyris mesacostalis* (Williams, 1887; Butts, 1903; and Woodruff, 1942) and is probably a time-stratigraphic correlative of the "Bradford First" sand (Fettke, 1938); and (b) the Alfred Station Coquinite lies in the stratigraphic horizon of the Rushford Sandstone, which may be a time-stratigraphic correlative of the "Bradford Third" sand.

The writer believes that each of these beds is essentially coeval throughout its lateral extent, and that the intervening strata represent contemporaneous deposition throughout Allegany County and adjacent areas. The McHenry Valley Substage of the Cassadaga Stage is the proposed time-stratigraphic name for the strata between and including the older Alfred Station Coquinite and the younger Cuba Formation (Fig. 1). It is

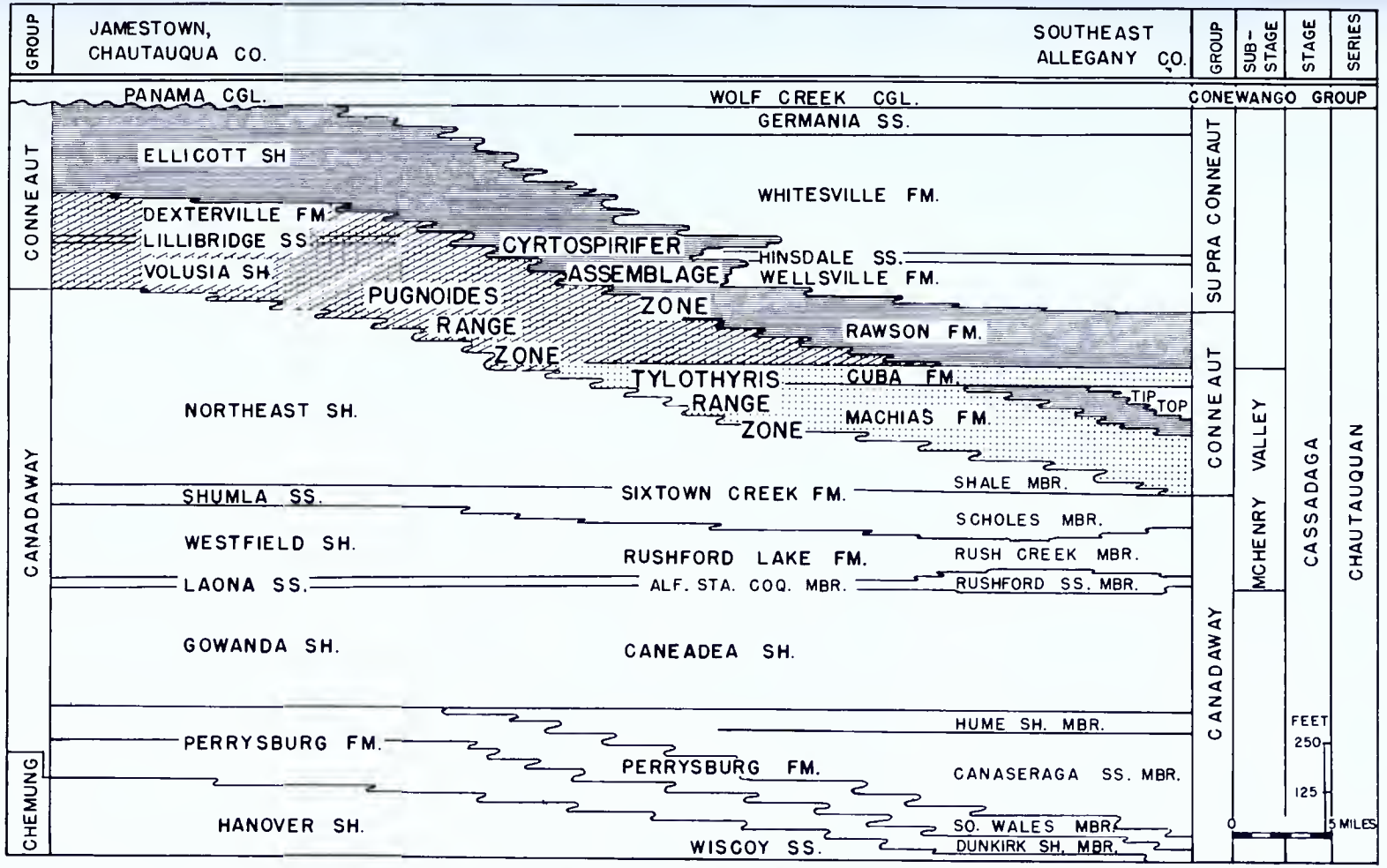


Figure 1. Correlation chart of Chautauquan Series from southeastern Allegany County to Jamestown, Chautauqua County, New York.

named from exposures along McHenry Valley in Almond and Alfred Townships, Allegany County (Fig. 2, sec. 10).

Rock-Stratigraphic Units

Three groups, each differing by some objective physical criteria, are recognized in the area of study. In ascending order, the groups and their major rock types are: (1) black and gray shales with sole-marked sandstones and siltstones, a thin but widespread coquinite, a shoestring sand, and blanket-like sandstones and shales of the Canadaway Group; (2) fossiliferous sandstones and mudstones with barren shales of the Conneaut Group; and (3) "Catskill" type beds of the Supra Conneaut (informal usage).

Supra Conneaut

Included in this grouping are the beds between the base of the Wellsville Formation and the base of the Wolf Creek Conglomerate along the Genesee Valley (Fig. 1). The sequence, although not studied in detail, is about 500 feet thick and is lithologically transitional between the fossiliferous strata of the underlying Conneaut Group and the overlying Cattaraugus red beds. Woodruff (1942) correlates these beds with the Conneaut Group of Chautauqua County. Present studies indicate that this correlation may be erroneous. Evidence will be offered below to support a Conneaut relationship with the group of rocks that underlie the Wellsville Formation (Fig. 1).

Hinsdale Sandstone

The Hinsdale Sandstone (Chadwick, 1933b) is 15 to 30 feet thick, fine-grained, in part pebbly, massively bedded, and red-brown to chocolate-colored. It occurs about 250 feet above the Cuba Formation (Figs. 2 & 3).

Wellsville Formation

The Wellsville Formation was named by Woodruff (1942), who states that although it is "...somewhat similar to the Machias beds below,... there is some indication of approaching 'Catskill' deposition, as a few of the beds in the upper part have a chocolate-brown to dull-red color,..." (p. 32). The formation (as defined by Woodruff) is about 250 feet thick, containing gray-colored interbeds of sandstone, shale, mudstone, and coquinite near the lower contact and siltstone and red-brown shale near the upper contact. Because the coquinite-mudstone association characterizes the older Machias Formation and the red-brown shale characterizes the younger "Catskill" beds, the lower contact of the formation must be redesignated to provide greater unity and greater practicability to the

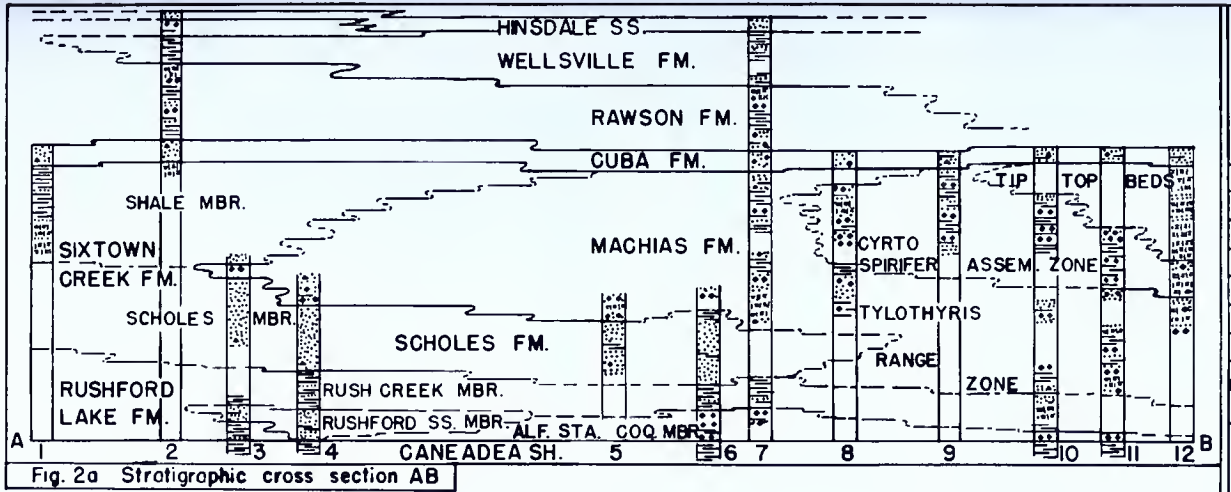


Fig. 2a Stratigraphic cross section AB

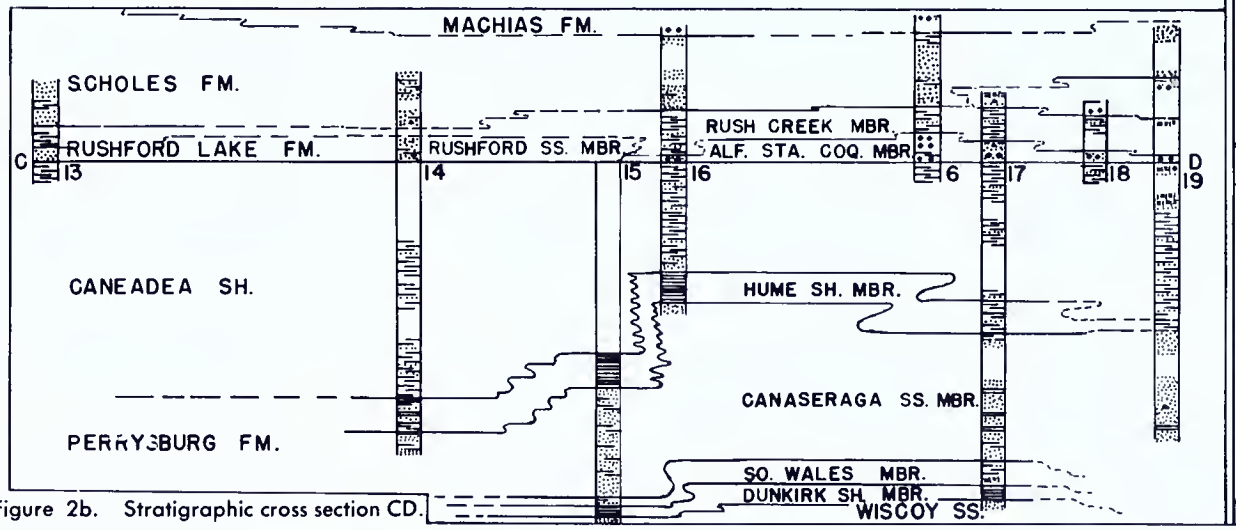
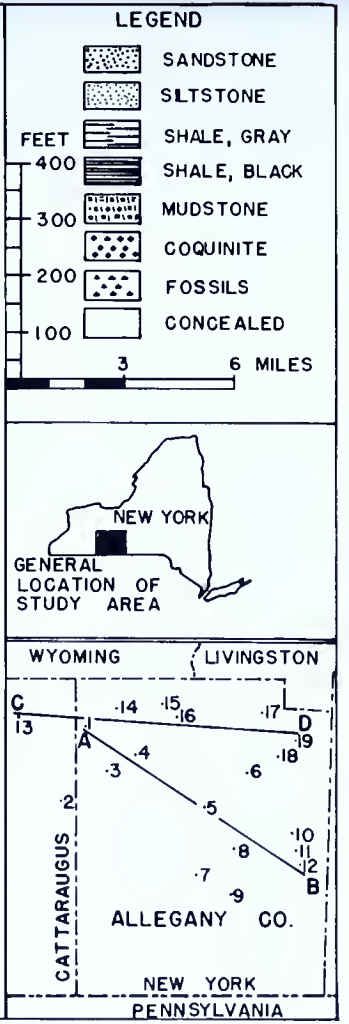


Figure 2b. Stratigraphic cross section CD.



rock classification and to place these different rock types into their respective groups. The new contact is placed above the topmost stratum resembling the Machias; the remaining beds are assigned to the Rawson Formation (new name) of the Conneaut Group. The two formations complement each other in thickness with the Wellsville Formation thinning to the west from a depositional high in eastern Allegany County (Figs. 2a & 3).

Conneaut Group

The Conneaut Group was named by Chadwick (1935b) to include the unfossiliferous Girard Shale and the overlying Chadakoin beds of northwestern Pennsylvania. Eastward into Jamestown, New York, it includes the fossiliferous Cuba, Volusia, Hinsdale, and Chadakoin Formations (Chadwick, 1935a). Farther east in Allegany County, where the group is "intersected" by the McHenry Valley Substage, it is about 500 feet thick and is marked by the very fossiliferous Rawson, Cuba, and Machias Formations (Fig. 1).

Rawson Formation

The Rawson Formation is named from exposures along an east-flowing tributary of Oil Creek, 0.8 mile south-southwest of Rawson, Cattaraugus County, New York. The formation, which is wedge-shaped, everywhere overlies the Cuba Formation; it underlies and interfingers with the Wellsville Formation in Allegany County and underlies the Hinsdale Sandstone in Cattaraugus County (Figs. 2a & 3). It appears to be a rock-stratigraphic correlative of Butts' (1903) Zone 11 and Chadwick's (1934) Cadiz beds.

The following description of the Rawson Formation type section serves as a guide of the formation's general lithology.

Thickness in Feet	Description
7	Sandstone (Hinsdale), gritty, poorly consolidated, and weathering to a dull chocolate color.
34	Concealed zone (Rawson Formation); the stream channel is laden with coquinites and sandstones.
32	Shale (Wellsville tongue), gray with thin interbeds of light-gray siltstone.
2	Sandstone and coquinite interbeds.
22	Shale, gray, silty, and fossiliferous; contains interbeds of sandstone, siltstone, and coquinite.
12	Siltstone, gray with thick interbeds of fossiliferous mudstone.
14	Sandstone, gray, fossiliferous, fine- and medium-grained, and massively bedded; contains intercalations of coquinite, mudstone, siltstone, and gray shale.
22	Sandstone, gray, fine-grained, ripple-marked, channel-grooved, sole-marked (strike N.49° – 52° W.), massively bedded and intercalated with mudstones and coquinites.

4	Mudstone, gray, silty, micaceous, and fossiliferous.
36	Sandstone, gray, thick- and massive-bedded, fine-grained near upper contact; coarse-grained and pebbly near lower contact; contains mudstones and coquinites near contacts.
36	Shale, gray, weathering brown to rust.
41	Sandstone (Cuba Formation), gray, clay-galled, fine-grained, fossiliferous, ripple-marked, and sole-marked; elevation at lower contact 1630 feet.

The Rawson Formation is lithologically and paleontologically similar to the *Cyrtospirifer* Assemblage Zone of the Machias Formation. Although the two formations are almost indistinguishable without the presence of the intervening Cuba Formation, the faunal association of *Cyrtospirifer, Schuchertella,* and *Chonetes* suggests the presence of the Rawson rather than the Machias. The Cuba-Rawson contact, where concealed, may be inferred from a *Schuchertella*-rich zone about 35 feet above the lower Rawson contact. Poorly exposed Rawson-Wellsville contacts were placed at the highest concentration of coquinites.

Cuba Formation

The Cuba Formation was: (1) originally described by Williams (1887); (2) designated the Cuba Sandstone, "...a lentil in the Chemung formation.", by Glenn (1903, p. 969); and (3) redefined the Cuba Formation by Woodruff (1942). The writer agrees with the rank designation of Woodruff and the tacit implication of Glenn. The formation is about 40 feet thick, blanket-like, and is composed of lenticular gray siltstones and shales with thick-bedded, coarse-grained feldspathic and fossiliferous sandstones.

The formation occurs about 250 feet below the Hinsdale Sandstone and about 500 feet above the Alfred Station Coquinite (Figs. 2a & 3). It normally contains or is proximal to the last occurrence of *Tylothyris mesacostalis,* which is the most common fossil in the area of study. These unique relationships make this thin but widespread horizon a workable time-stratigraphic plane.

Machias Formation

Chadwick (1923) named the Machias Formation, in the region of Machias, Chautauqua County, for the fossiliferous phase of the Northeast Shale. The writer acknowledges the name Machias Formation, recognizes the virtually nonexposed Machias in the type region as a tongue or a group of tongues with southern roots, and retains with reluctance the geologically engrained but heretofore nondescript Machias as a formation. He further regards the upper reaches of the McHenry Valley Creek in eastern Allegany County as the standard locality of the formation (Fig. 2a, sec. 10).

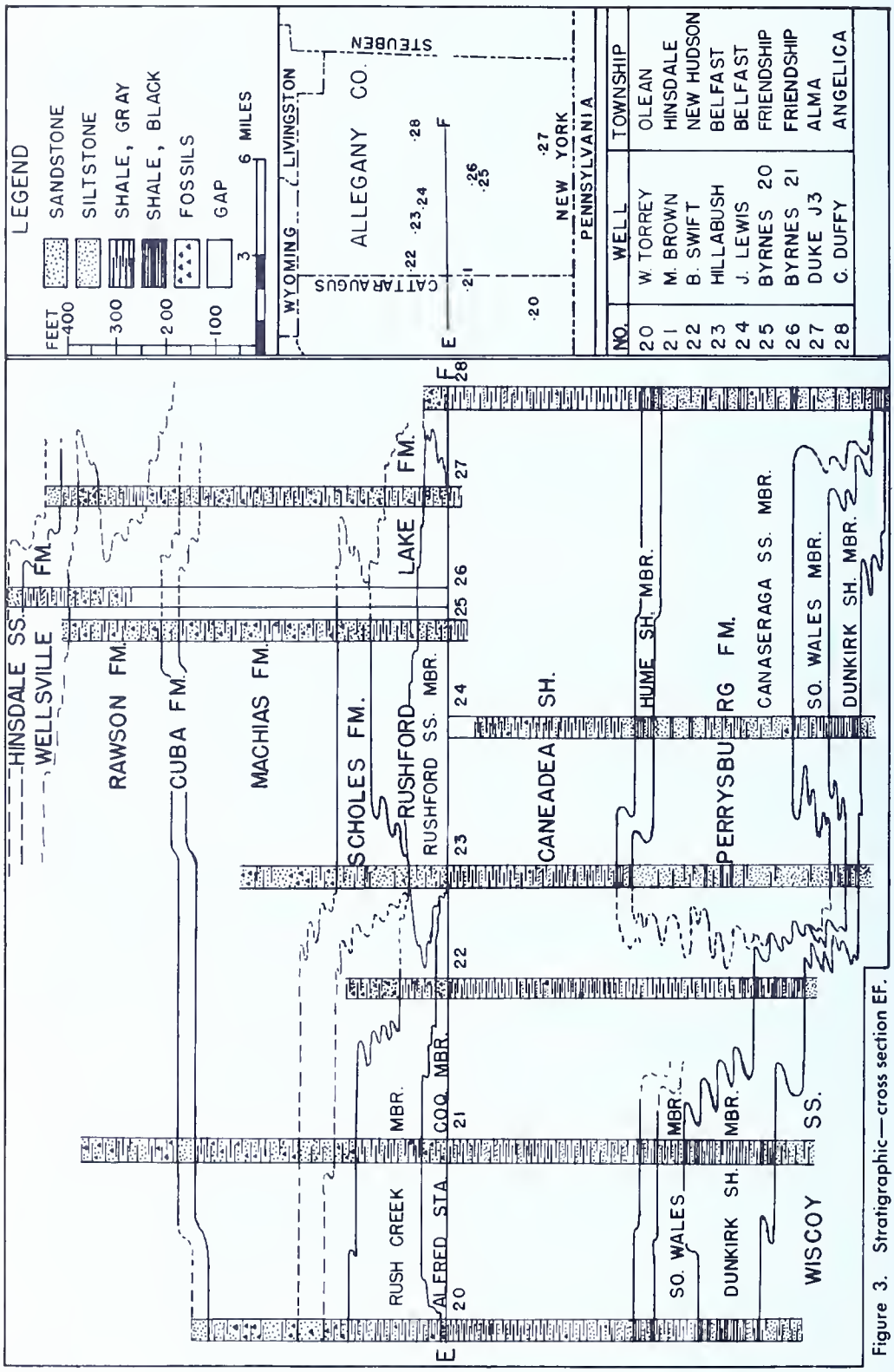


Figure 3. Stratigraphic—cross section EF.

The herein redefined Machias Formation is a 400-foot wedge-shaped body that is abundantly fossiliferous. It is thickest along a northeast-southwest line in south-central Allegany County and thins to the northwest and west at a rate of about 7 and 3 feet per mile respectively (Figs. 2a & 3). The formation overlies and interfingers with the Sixtown Creek formation to the northwest (Fig. 2a), overlies the Rush Creek Member to the west (Fig. 3) and east (Fig. 2a), and underlies the Cuba Formation throughout the area.

The Machias, which is characteristically coquinitic, is recognized in well samples by the concentration of shell fragments. Light-gray massive-bedded mudstones, massive-bedded clay-galled sandstones, and light-to dark-gray and olive-green shales with siltstone interbeds constitute other major rock types within the formation. Commonly, the sandstones and mudstones are fossiliferous and the shales are barren. Interference-ripple marks and flow rolls are common primary structures; sole marks are rare.

Tylothyris mesacostalis and *Cyrtospirifer* spp. are the most common brachiopods in the area. The apparent stratigraphic zonation of these fossils in the field led the writer to make a statistical study of their abundance. In 132 field specimens, it was found that *Cyrtospirifer* spp. and *T. mesacostalis* occur respectively in 52% (69 of 132) and 62% (82 of 132) of the collection, and that the two forms are associates in 20% (27 of 132) of the collection. The results, however, are misleading and do not account for the spacial distribution of each of these principal forms. For example, *Cyrtospirifer* spp. occur in every specimen (15 of 15) from beds younger than the Cuba Formation and in 91% (20 of 22) of the collection from beds west of the Tip Top beds (Fig. 2a). It is significant, however, that *T. mesacostalis,* which is the most common fossil in the area, is conspicuously absent from these same sections. *Tylothyris* apparently was restricted in time and in space. If consideration is given to this factor, then *Tylothyris* could not occur in more than 95 (132 – [22+15]) of the 132-fossil collection. Of this number, it is found 82 times, while *Cyrtospirifer* is found only 34 times; the two forms are associates in 28% (27 of 95) of the collection. Although the data are not completely definitive, they strongly suggest the presence of two biostratigraphic zones and possibly two faunal zones: a *Tylothyris* Range Zone and a *Cyrtospirifer* Assemblage Zone.

Biostratigraphic zonation is best developed and most clearly defined in southeastern Allegany County. It is less evident to the northwest, where a limited zone of co-mixing and/or co-mingling of *Tylothyris* and *Cyrtospirifer* probably occurred. The presence and position of these zones appears to be an expression of the Tip Top beds of the Machias Formation (Fig. 2a). The name, Tip Top, comes from the named drainage divide in Alfred Township, Allegany County. The Tip Top is a nonfossiliferous

wedge-shaped body containing mudstones and red beds. It occurs below the Cuba Formation and is 175 feet thick in section 12 of Figure 2a. It thins to the northwest and probably occurs lower in section in Steuben County, to the southeast.

The vertical and lateral ranges of *T. mesacostalis* define the limits of the *Tylothyris* Range Zone, and set in effect the limits of the *Cyrtospirifer* Assemblage Zone (Stratigraphic Code, 1961). The upper contact of the Cuba Formation coincides with the upper limit of the range zone and the lower limit of the assemblage zone (in the Rawson Formation; Fig. 1). The lower limit of the range zone is not set, but *T. mesacostalis* occurs throughout the Canadaway Group. The limits of the assemblage zone in the Machias Formations vary considerably; it underlies the Cuba Formation and is proximal to a massively bedded sandstone, possibly the "Bradford Second" sand (Fig. 2a). Because the fossiliferous Conneaut Group is overlain and underlain by relatively nonfossiliferous strata and contains both biostratigraphic zones, it is practical to limit the contacts of these zones to the group (Fig. 1).

Canadaway Group

Chadwick (1933a) named the Canadaway Group for the " . . . pseudo-Chemung, later beds, from the base of the Dunkirk to the base of the Cuba sandstone . . . " (1935b, p. 351). Whereas the Chemung-Canadaway contact is well established lithologically, controversy has centered about the Canadaway-Conneaut contact. The " . . . loss of '*Spirifer*' *mesacostalis* and accession of *Camarotoechia duplicata* . . . seems to define the base of the group Conneaut." (Willard, 1939; p. 252).

It is obvious that Chadwick did not define a group but instead defined a biostratigraphic unit. The long listing of diagnostic Canadaway fossils in Chadwick's (1935a) paper "Faunal Differentiation in the Upper Devonian" shows his real intent. The use of present day rock-stratigraphic terms for biostratigraphic divisions was common procedure of the day, and it is only lately that this practice is not accepted. During the almost 30 years since Chadwick named the Canadaway Group, a number of geologists have studied the rocks under question and have applied rock-stratigraphic names to biostratigraphic divisions. This was contrary to the appeal of the Committee on Stratigraphic Nomenclature, 1933 and is contrary to the recommendations set forth in the Stratigraphic Code of 1961.

The *Tylothyris mesacostalis* and Cuba association led Woodruff (1942) to mark the upper Canadaway contact with the top of that formation. Tesmer (1955), using faunal criteria, likewise assigns Cuba-to-Dunkirk limits to the Canadaway and relegates the group to formation rank. Rickard (1957), with reservation, tentatively places the Conneaut-

Canadaway contact at the top of the Cuba. Recently (1962), the Geological Survey of New York placed the contact at the base of the Cuba Formation.

The writer accepts, with reservation, all the above-mentioned designations of the Canadaway-Conneaut contact. He declines, however, to accept the above classifications on the grounds that none is defined along rock-stratigraphic criteria and that none possesses, except very locally, significant lithologic limits. The Cuba " . . . a lentil in the Chemung formation" (Glenn, 1903) cannot be considered seriously as a marker of the contact because: (1) it is relatively thin and lies essentially parallel to time-stratigraphic planes; and (2) the lithologic group confining the Cuba (implicit in Glenn's statement) is some 500 feet thick transgressing both time and the Cuba Formation to the west (Fig. 1). Consequently, Cuba contacts (top or bottom) are relatively insignificant in defining the lower contact of the Conneaut Group, which is placed at the base of the first thick and continuous sequence of fossiliferous strata—the Machias.

The upper contact of the Canadaway rises westward at a rate equal to the rate of thinning of the Machias, which is about 7 feet per mile to the northwest and 3 feet per mile to the west. By projecting an average rate of thinning of 5 feet per mile, the Cuba theoretically should be the youngest formation of the Conneaut Group and the oldest formation of the Canadaway Group near Jamestown, New York. Significantly, the Cuba never has been identified as far west as Jamestown, which is the standard section of the Conneaut Group, and probably pinches out before attaining its position as a reference marker of the Canadaway-Conneaut contact. The formation appears only locally to be the youngest formation of the Conneaut Group in northwestern Allegany County (Fig. 2a).

The Canadaway Group includes the Sixtown Creek, Scholes, and Rushford Lake Formations (new names), Caneadea Shale, and Perrysburg Formation. The group was deposited prior to and partly during the McHenry Valley Substage (Fig. 2).

Sixtown Creek Formation

The Sixtown Creek formation (informal usage) is a wedge-shaped body that thins south from a depositional center in northeastern Cattaraugus and northwestern Allegany Counties, where it is about 400 ± 50 feet thick (Fig. 2a). The formation is nonfossiliferous and is the northern time-stratigraphic complement of the Machias wedge (Fig. 2a). The formation overlies the Rushford Lake Formation, underlies the Cuba Formation, and interfingers with the Machias Formation.

Although formal recognition is not requested for this formation, because it is neither well nor fully exposed, stream bed and hillside occurrences confirm its presence in northern Allegany and Cattaraugus

Counties. It is tentatively divided into an older sandstone member and a younger shale member.

Shale Member—This member is approximately 200 feet thick and is composed of gray shales and mudstones with thin sandstone interbeds. Occasionally, the shales weather red brown, and the sandstones are ripple-marked. The member is sparsely fossiliferous near Machias, New York, where these beds are interpreted as northern extending tongues of the Machias Formation and are not an integral part of the member.

Scholes Member—The Scholes member is named for the 130-foot sequence of nonfossiliferous massively bedded sandstones and gray shales exposed along a south-flowing tributary of Black Creek, 0.5 mile south of Scholes in Allegany County. The member is thickest in northern Allegany County and thins to the south, where it is pervaded by tongues of the Machias. Some of the more massively bedded sandstones in the lower half of the Machias Formation may be tongues of the Scholes. The designation of member rank is applicable only where the Scholes is overlain by the shale member of the Sixtown Creek formation; elsewhere, especially in central Allegany County, the Scholes attains formation rank (Fig. 2a and 3).

Formal recognition of this formation is requested, because it is a significant part of the stratigraphic section and is well-exposed throughout the area of study. A description of the Scholes Formation type section is as follows:

Thickness in Feet	Description
18	Sandstone (Machias Formation), gray, thick- and massive-bedded, fossiliferous, and intercalated with thick beds of coquinite.
23	Concealed zone.
19	Shale (Scholes Formation), olive green to gray, and fissile.
17	Sandstone, gray, massively bedded (avg. 5 ft.), and worm-burrowed; siltstone interbeds are common near the contacts.
8	Concealed zone.
6	Mudstone, gray, blocky with sandstone lenses near upper contact.
18	Sandstone, gray, thick- and massive-bedded.
25	Concealed zone.
37	Sandstone, gray, coarse-grained, and massively bedded (avg. 8 ft.).
55	Shale, (Rush Creek Shale Member of the Rushford Lake Formation), gray to dark gray, fissile and interbedded with worm-burrowed and clay-galled sandstones.
51	Interbeds of coquinite, fossiliferous sandstone, mudstone, shale, and siltstone (Alfred Station Coquinite Member of the Rushford Lake Formation).
9	Concealed zone.
12	Shale (Caneadea Shale), brownish gray and silty; elevation 1625 feet.

Massive beds, on the order of 5 to 15 feet thick, are the most pronounced structural feature of the formation. Sole marks, ripple marks,

flow rolls, and clay galls are locally common. The average strike of 21 sole-mark azimuths and 9 ripple-mark axes is respectively N.15°E. and N.74°E. The average long axis of 11 flow rolls is similar to the average paleocurrent direction and strikes N.3°E.

Rushford Lake Formation

The Rushford Lake Formation (new name) overlies the Caneadea Shale and underlies the Scholes Formation of the Canadaway Group to the north and the Machias Formation of the Conneaut Group to the south (Figs. 2 & 3). At the type section, 300 feet south of the Rushford Lake and Caneadea Storage Dam on Caneadea Creek, two thick sandstone units are present and are separated by 73 feet of shale with siltstone and sandstone interbeds (Fig. 2a, sec. 4). The geometry of these sand bodies differs markedly. The younger sand, which is the Scholes Formation, is blanket-like; the older sandstone (the Rushford Sandstone) is a shoestring sand, which laterally gives way to a remarkably persistent coquinite bed, the Alfred Station Coquinite. The third member of this formation, the Rush Creek, overlies both the shoestring sand and the coquinite.

A description of the Rushford Lake Formation type section, which is also the type section of the Rushford Sandstone and Rush Creek Members of the formation and the typical section of the Scholes Formation, is as follows:

Thickness in Feet	Description
82	Sandstone (Scholes Formation), gray, massively bedded (avg. 8 ft.).
26	Sandstone, gray, massively bedded (10 to 15 ft.), fossiliferous.
54	Shale (Rush Creek Member of the Rushford Lake Formation), gray and silty with numerous interbeds of dark gray micaceous and slightly fossiliferous siltstone and sandstone; the approximate shale, siltstone, and sandstone percentages are 45%, 35%, and 20% respectively.
6	Sandstone, light gray, thin-bedded, sparsely fossiliferous, and intercalated with light-gray silty shales.
13	Shale, mudstone, and siltstone interbeds; light-gray silty mudstones with siltstone interbeds are prominent in the lower 4 feet; blue-gray shales with siltstone interbeds are common in the remainder of the bed.
23	Sandstone (Rushford Sandstone Member of the Rushford Lake Formation), gray, massively bedded, and micaceous; the bed grades laterally into shales with sandstone interbeds.
13	Shale, gray, and silty with intercalations of thin sandstone beds.
10	Sandstone, gray, massively bedded (avg. 4 ft.), flow-rolled near upper contact; intercalations of shale are common.
4	Mudstone, gray, blocky, and very silty.
3	Sandstone, gray, clay-galled, massively bedded; the bed grades laterally into shales with siltstone and sandstone interbeds, bearing flute casts that strike N. 18° W. (steep side south); flow rolls with long axes oriented N. 20° W.; and groove casts that strike N. 88°E.
132	Shale (Caneadea Shale), gray with few siltstone and sandstone interbeds.

Rushford Sandstone Member—The Rushford Sandstone (Luther, 1902) consists of massive-bedded fine-grained sandstones with subordinate shale beds. The member occurs along a N. 20° W. belt two to three miles wide and at least 30 miles long (sec. 14, Fig. 2b and sec. 27, Fig. 3). Although the sandstone is recorded near Elton, New York (Fig. 2b, sec. 13), it may not be genetically related to the shoestring sand that traverses the region in a northwest direction, passing through the type locality. Flute casts at the Elton Section strike N. 35°E., indicating a northeast-transport direction for that sand. Southwest of the type locality, and perhaps southwest and northeast of the shoestring sand, the member is thin-bedded and lenticular; sole marks, flow rolls, worm burrows, and clay galls accompany this change.

The member crops out at three sections and is also recorded in cuttings from three wells (Figs. 2 & 3). Commonly, the sand is gray, but in the Duke J3 and Byrnes No. 20 Wells it is pink to red-brown.

Alfred Station Coquinite Member—The Alfred Station Coquinite Member is remarkably persistent. It occurs throughout the area, except along the narrow belt of the Rushford Sandstone Member (Figs. 2 & 3). The member is easily recognized in the field and in well studies as a massively bedded coquinite about 6 feet thick or as a coquinite, sandstone, mudstone, and shale sequence about 50 feet thick. It occurs about 500 feet below the Cuba Formation within a thick sequence of nonfossiliferous shales, sandstones, and siltstones. Sandstones are locally abundant. Its fossil content is variable, normally containing an abundance of *T. mesacostalis*. In contrast, *Cyrtospirifer* species are absent to rare.

At the type locality (along Caneadea Creek in Alfred Station, Allegany County) the member occurs within a clearly defined channel about 400 feet wide and 10 feet deep and consists of cross-bedded and flow-rolled coquinites and sandstones. The dip direction of cross stratification planes and the axis of flow rolls strike N. 58°E. Because the lower contact of this member is used as a stratigraphic-datum plane, it appears to have a flat lower contact and a convex-upward upper contact (Figs. 2 & 3). Another, and possibly a more accurate, interpretation is that the member has a concave-upward lower contact and a flat upper contact.

Rush Creek Member—The Rush Creek Member is named from exposures along Rush Creek in Allen Township, Allegany County. Because the section (sec. No. 16, Fig. 2b) is poorly exposed in the creek and is inaccessible for study, the type section of the member is at Rushford Lake. The member has well-defined contacts and is lithologically similar to the underlying Caneadea Shale, from which it is separated by the Alfred Station Coquinite or the Rushford Sandstone (Figs. 2 & 3). Both in well studies and at the outcrop, the contacts are drawn along massive beds of sandstone (Rushford and Scholes) and coquinite beds (Alfred Station and

Machias). Gray silty shale with thin interbeds of sandstone and siltstone constitute the greater part of the member.

The member cannot be recognized in the Hillabush Well (Fig. 3, sec. 23) and may not be present in the Sixtown Creek Section (Fig. 2b, sec. 14). It thickens westward at a rate equal to the rate of thinning of the Machias Formation (Fig. 3).

Caneadea Shale

The Caneadea Shale (Chadwick, 1933b) is composed of fissile gray shale with numerous interbeds of siltstone and sandstone, and an occasional olive-green, black, and red-brown-weathering shale. The siltstones and sandstones are commonly thin-bedded, laterally persistent, sole-marked, and ripple-marked. Cross-bedding, flow rolls, worm burrows, and fossiliferous strata are rare. The average strike of 88 sole-mark azimuths and 11 ripple-mark axes is respectively N. 86° W. and N. 39°E. Its thickness varies considerably and is contingent upon the thickness of the Canaseraga Sandstone and the presence of the Hume Shale (Figs. 2b & 3).

Perrysburg Formation

The Perrysburg Formation (as defined by Pepper and deWitt, 1951) includes three members (Dunkirk, South Wales, and Gowanda) in western Cattaraugus County and five members (Dunkirk, South Wales, Canaseraga, Hume, and Caneadea) in the Genesee River Valley. The writer excludes the Caneadea Shale from the formation, because it limits the formation, which is characterized by black shale, to one with black shale contacts (Dunkirk and Hume).

Although the unnamed black shale unit at the upper contact of the Perrysburg Formation in Cattaraugus County and the Hume Shale of Allegany County may be time-stratigraphic equivalents (Fig. 3), they are not rock-stratigraphic correlatives because they are neither homotaxial nor laterally continuous. The South Wales Member is not homotaxial with eastern sections or continuous in wells (Fig. 3), but it does crop out continuously along latitudes north of the area of study (Pepper and deWitt, 1951).

Hume Shale Member—The Hume Shale (Pepper and deWitt, 1951) is best exposed and most typically developed in northwestern Allegany County. There the member is a black shale with intercalations of dark-gray to olive-green shale and layers of limestone nodules and septaria. Elsewhere (Fig. 2b), the member is interbedded with siltstones and sandstones.

Canaseraga Sandstone Member—The Canaseraga Sandstone Member (Pepper and deWitt, 1951) is a thick wedge-shaped deposit that thins to

the west and northwest from a depositional center probably in Steuben County. Siltstones and sandstones make up most of the member. They are laterally persistent, rhythmically bedded with shales, sole-marked, and ripple-marked. The average strike of 60 paleocurrent measurements and 13 paleoslope observations is respectively N. 90° W. and N. 34°E. The shales are commonly gray and silty. Petroliferous-black shales and coquinitic sandstones occur sporadically throughout eastern Allegany County.

South Wales Member—The South Wales Shale was named by Pepper and deWitt, 1951. It is composed essentially of gray and dark-gray silty micaceous shale with intercalations of calcareous nodules, black shale, and thin-bedded siltstone. The absence of the Canaseraga Sandstone and the Hume Shale from the Botens Swift Well makes it impossible to recognize the South Wales in that well (Fig. 3, sec. 22). Apparently, the Canaseraga Sandstone occupies the stratigraphic position of the member in the C. Duffy Well (Fig. 3, sec. 28).

Dunkirk Shale Member—The Dunkirk Shale was named by Clarke (1903), described by Luther (1903), and redefined by Pepper and deWitt (1951). It is 17 to 25 feet thick, black and thinly laminated shale with small ellipsoidal nodules. It rapidly thickens westward and is from 120 to 200 feet thick in wells of Cattaraugus County (Fig. 3). The relatively sharp Dunkirk-Wiscoy contact is one of the more useful stratigraphic horizons in the Upper Devonian of New York (Rickard, 1957).

Interregional Rock-Stratigraphic Correlation

It is essential in any logical interregional correlation to recognize the fundamental and generally accepted principle that most Upper Devonian rock-stratigraphic units of New York and Pennsylvania are time transgressive. The lower contact of the Conneaut Group attests to such a transgression.

If there is a consistency of lithology and uniformity of transgression beyond the confines of this study, then the Conneaut Group should occur time-stratigraphically younger to the west and older to the east. The supposition appears correct, for coquinitic strata do occur along these projections (Bradley and Pepper, 1938 and Willard, 1939).

Coquinitic strata first appear in abundance in Chautauqua County at the base of the Conneaut Group (Chadwick, 1935a; Caster, 1934; and Tesmer, 1955). Accompanying this influx of fossiliferous strata is the " . . . loss of *Delthyris mesacostalis* and accession of *Camarotoechia* (?) *duplicata*, . . . " (Chadwick, 1935b).

The writer considers the Machias, Cuba, and Rawson Formations of Allegany County to be a rock-stratigraphic correlative of the Conneaut Group at its standard section near Jamestown in Chautauqua County,

because: (1) both units represent a distinct and a similar lithologic break at their respective localities; (2) the Conneaut Group of Chautauqua County is about 420 feet thick, is characterized by an abundant fauna, and except for the Lillibridge Sandstone, is lithologically similar throughout its vertical extent (Caster, 1934 and Tesmer, 1955). These characteristics are similar to those of the Machias, Cuba, and Rawson Formations of Allegany County; and (3) the base of the Conneaut at Jamestown is about 45 miles west of and 200 feet stratigraphically higher than the base of the Machias Formation (measured from the base of the Dunkirk Shale at the W. Torrey Well (Fig. 3, sec. 20)). Significantly, the lower contact of the Conneaut Group from the Duke J3 Well to the W. Torrey Well (Fig. 3) and from section 10 to section 3 of Figure 2a rises respectively 7 and 3 feet per mile and is comparable to the theoretical ascent of the group from the W. Torrey Well to Jamestown, which is about 4.5 feet per mile.

Although the faunal break at the base of the Conneaut Group has no significance in rock-stratigraphic designations, a review of the literature indicates that the fossils of the group in Chautauqua County fall into two biostratigraphic units: the *Camarotoechia* or *Pugnoides* (which appears to have been placed in synonomy with *Camarotoechia*) range zone and the *Cyrtospirifer* assemblage zone (informal usage). The following quotations from Caster (1934, p. 66) support this statement: The Dexterville (Fig. 1) " . . . is characterized in the area about Jamestown by the abundance of brachiopods of many sorts, of which *Camarotoechia duplicata* is particularly numerous." and "The fauna of the Ellicott is inadequately known, but is characterized in the type locality by the abundance of pelecypods and a mutational form of 'Spirifer disjunctus'. The rather abrupt faunal change at the top of the Dexterville . . . seems to be good basis for the differentiation of a new member." Tesmer (1955, p. 14) concurs with Caster and states that: "*Pugnoides duplicates* serves as an index fossil for the Dexterville." and "The base of the Ellicott is placed at the last appearance of *Pugnoides duplicates* . . . Although at first glance the Dexterville and Ellicott faunas appear to be similar, it is worth noting that the Ellicott is characterized by an abundance of *Cyrtospirifer* which occurs only sporadically in the Dexterville, . . . "

A projection of these biostratigraphic units into Allegany County indicates that the *Cyrtospirifer* Assemblage Zone extends throughout the group's upper 225 feet of strata, while the *Tylothyris* Range Zone gives way laterally and in time to the *Pugnoides* range zone (Fig. 1). The proposed correlation appears to be lithologically and paleontologically consistent throughout these widely separated regions.

Furthermore, since the Panama or the Wolf Creek Conglomerate (Conewango Group) overlies the Conneaut Group of Cattaraugus County and the Supra Conneaut of Allegany County (Caster, 1934; Cooper et al.,

1942; and Woodruff, 1942) then an erosional unconformity or a zone of nondeposition or both, on the order of 450 feet, must be present below the conglomerate west of Allegany County (Fig. 1). The red bed and conglomerate association makes the erosional theory more tenable than theories of nondeposition.

The following statements from Caster (1934) lend support to the erosional theory, and in effect they enhance the entire stratigraphic scheme proposed in this paper. "At the top of the Ellicott shale there is an hiatus above which occurs the first member of the Conewango series [Group], the Panama conglomerate . . . There is a greater westward facies off-set between the upper Chadakoin [Ellicott] and lower Conewango [Panama] than at any point in the Upper Devonian of this region below the base of the Mississippian. The faunal off-set is naturally in accord with the facies disconformity. The Chadakoin species which carry over into the basal Conewango are for the most part appreciably altered, thus suggesting at least a slight unrecorded interval. Many new forms appear suddenly in the midst of the Upper Devonian mutants. These new elements do not occur, so far as known, in the Chautauquan series."

The hiatus may be substantially greater than suggested by Caster; as a minimum, it represents the time required to erode the strata of the Supra Conneaut and to evolve these many new forms suggested by Caster. The Devonian-Mississippian contact long has been controversial. It was placed at the bottom of the Conewango Group by Butts (1903), Clarke (1903), and Goldring (1931) and at the top of the group by Caster (1934) and Cooper et al. (1942). All designations of the contact were based on faunal criteria. The physical evidence presented in this paper may throw new light on the problem.

Furthermore: (1) other rock-stratigraphic correlations, shown in Figure 1, appear valid by virtue of their gross lithology and their stratigraphic position; (2) the Alfred Station Coquinite, which is anomolous in the generally barren Canadaway Group, may be a tongue of the eastward descending Conneaut Group; and (3) the Tip Top beds may be a tongue of the eastward descending Supra Conneaut.

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Upper Devonian Stratigraphy and Structure in Northeastern Pennsylvania

ABSTRACT

This is a report of progress concerning research not yet completed. It contains two sections, one relating to stratigraphy, the other proposing certain structural relations that are suggested by stratigraphic and tectonic inferences. The first of these sections is reasonably factual, the second is almost entirely conjectural.

Regarding stratigraphy: Traced eastward towards Delaware River from northwestern Pennsylvania, true chronologic or time-stratigraphic units so thicken that their total thickness would be nearly trebled if other factors were not involved. They do not attain this maximum increase, for at some midpoint near the 78th Meridian, they are truncated by an erosion surface above which a group of late Devonian arenaceous rocks enters the column below the Mississippian contact. The latter continues to rise eastward above in-coming Pocono-like sediments.

West of the 78th Meridian these time-stratigraphic units more or less coincide with several lithic facies or rock-stratigraphic units. Whereas the former rise progressively higher above the Hamilton east of this meridian, the lithic facies commence to transgress downward at about the same point, so that the two types of rocks diverge from each other in the column, the chronologic units rising toward a terminal unconformity, the lithic facies descending toward (and even below) the base of the Upper Devonian. Unless recognized, this divergence is a confusing element in stratigraphic studies.

Regarding structure: Some—perhaps too small—evidence is presented in support of one or more major faults that may affect the rock section below the unconformity noted above but do not involve the highest Devonian or the Pocono. This faulting, it is believed, could explain certain critical differences between Upper Devonian rocks in their easternmost Pennsylvanian development and sections in central and western Pennsylvania.

As the faulting may have taken place before the late Paleozoic folding, it is suggested that its sedimentary effects may now have become dislodged from their original site immediately above the corresponding rift in the basement. A new method of studying this possible situation is described. It involves the simultaneous use of two maps on transparent media, one a normal geologic map, the other plotted on a palinspastic base which eliminates the effects of subsequent folding.

If a structural line on the geologic map is transferred to its appropriate coordinates on the Palinspastic map and this new line is then traced back on the geologic map, one can readily compare two possible results of a single event that may have become separated by later deformation. This is suggested as a new and useful approach to the interrelations of structure and stratigraphy where there has been pattern deformation as in Pennsylvania.

GENERAL EXPLANATORY STATEMENT

Although this present study relates stratigraphy and structure for Upper Devonian rocks in northern and northeastern Pennsylvania and southern

and southeastern New York, it did not start with this aim in mind. Instead, it was commenced nearly 50 years ago when the writer as a student and protege of George Halcott Chadwick was first introduced to the fascinating problems of Devonian correlation between western New York and the Catskill Mountains. He was then advised by Chadwick that here was an almost virgin preserve wide open for stratigraphic investigation and research.

There was added impetus in the early 1940's when the writer compiled a monograph on the Devonian System of West Virginia (1943) and was again in close touch with Chadwick with whom he discussed many elements of Devonian stratigraphy across the Appalachian basin. Ten years later the writer's attention was specifically directed to the Pocono-Catskill region as a potential area for oil and gas exploration, and after examining existing literature and maps, he again became aware how little had been done to develop the regional stratigraphy of this large area.

In 1955 he prepared some stratigraphic cross-sections for the region in question completing these in draft form only, as the basic data were rapidly multiplying. Transcontinental Gas Pipe-line Company had commenced a drilling program which eventually led to eight deep wells in the Delaware Valley region, their data filling a large gap in subsurface information. Dr. Charles Fettke (1933–1961) was actively completing his excellent studies of deep drilling elsewhere in Pennsylvania, and the writer himself spent several months in the field measuring new sections, examining old outcrops, and generally increasing his interest in the problem.

Eleven regional cross-sections emerged from this early effort, but while certain major elements of the stratigraphy were plain to see, other matters were not at all clear and various limiting factors rose into view. One of the latter was the likelihood that the stratigraphy of this complicated region was destined to be resolved from subsurface studies rather than from surface observations. Another was the recognition that some major complications had not yet been identified.

In 1958–1959 the writer set the Devonian project aside to complete a comparable study of Cambro-Ordovician rocks in the southeast interior plateau region, during which he became aware of the strong control on stratigraphy by deep structures not visible at the surface. This led him to reappraise the Devonian project on which he felt a new approach should be tried.

Thus he again assembled detailed information for about 150 wells or surface measured sections, spaced geographically so there were several points of control for each county in the region. For locations east of about West Longitude 78°, these data were plotted on standard well-log strips at a vertical scale of 100 feet per inch. These long strips were then

arranged side by side so that detailed correlations and horizontal matchings could be tested. Later the entire assemblage was reduced for convenience to miniature well-strips about 30 inches in length, with their data plotted at a vertical scale of 600 feet per inch.

Fifteen new detailed sections were prepared criss-crossing the area from east to west and from north to south. Simultaneously, a matching set of isopach maps was initiated so that possible correlations could be studied in their proper regional relations. It was now found necessary to gross over a multitude of individual correlations and stratigraphic interfingerings in favor of the overall regional picture, but these smaller matters were not part of the writer's agenda anyway.

Two of the previous complicating factors became more plain. First, it was now clear that the top of the Devonian was incoherent. Beds called "Oswayo" at one place were called "Pocono" at another, while some "Pottsville" sandstones were clearly at the Pocono level. Time had to be taken to make a preliminary organization of the uppermost Devonian boundary and to ascertain the relations of Pocono horizons from one locality to another. Second, it became entirely plain that the stratigraphy did not continue undisturbed from the Allegheny Front to the synclinal inliers of the Broadtop and Anthracite Basins to the east. Instead, it was evident that stratigraphy and structure were closely interrelated in eastern Pennsylvania where even the largest structural elements were poorly known.

In August 1962 the writer again shelved the Devonian project to reconsider Appalachian tectonics in general, one outcome of which was the conclusion that a major dislocation may cross part of eastern Pennsylvania and that its age is likely pre-Pocono and post-Hamilton. This discovery immediately suggested that perhaps one missing element might be a concealed structural break or major fault not visible at the surface nor affecting the Pocono sediments. In consequence, the Devonian project was re-examined with this in mind and the present paper is a preliminary outcome. A more complete report is ultimately planned.

In many aspects this paper resembles "A Preliminary Subsurface Study of Southeastern Appalachian Interior Plateau" (Woodward, 1961) and is subject to the same limitations. The raw data—well logs, measured sections, etc.—used here are probably more reliable than those of the published study, but there are still too many points where the writer has nothing but his own interpretation to rely upon or where he may have overlooked matters of critical importance.

In the second place, the writer is charting a difficult course, namely that of pursuing by stratigraphic means structural patterns not reflected at the surface. As these matters can only be projected from accurate thickness and facies maps, both of which are extremely hard to come by, his

course is fraught with danger. Finally, as the structures sought are believed to antedate regional folding, and hence have been subject to subsequent change in position, any fabric woven from these weak threads becomes very thin indeed.

Despite these limitations it may be useful for a student of the Upper Devonian of Pennsylvania to examine this discussion, and the present paper has been printed with this thought in mind. If the writer is on the wrong track, it is his own fault for lacking wise caution; but if he is even partly right, a new and not previously described line of approach is offered for further use.

GROSS STRATIGRAPHIC RELATIONS

In treating the overall stratigraphy of the Upper Devonian of Pennsylvania, the first business is to establish a sequence of simple divisions that will be sufficiently elastic to accommodate both the known and any newly encountered complications as they are traced across the State. One such listing follows, differentiating seven time-stratigraphic units for northwestern Pennsylvania and western New York:

D. *PENNSYLVANIAN*..... "Olean," Pottsville, and higher units
Mauch Chunk

C. *MISSISSIPPIAN*..... Pocono
Knapp, Shenango

B. *LATE DEVONIAN*

7. Conewango..... Panama, Cattaraugus, Oswayo
6. Conneaut..... Girard-Volusia, Chadakoin
5. Canadaway..... Gowanda, Caneadea, Northeast, Machias
4. West Falls-Chemung..... Attica-Angola, Cayuta-Wellsburg
3. Sonyea-Portage..... Middlesex, Cashaqua, Enfield
2. Genesee..... Geneseo, Penn Yan, West River
1. "Tully" limestone

A. *MIDDLE DEVONIAN*..... (Hamilton, et seq.)

As the nomenclature of these divisions is not under present discussion, no attempt will be made to defend the groups or support their validity. They are chosen for convenience of discussion as almost all students of the Devonian will comprehend the condensed arrangement. Most of what is called "Tully" limestone is calcareous Genesee, and some of the driller's "Tully" runs as high as Genundewa. Nevertheless, as it is a familiar horizon in much of the literature, the Tully horizon deserves space in the rock column. Woodward thinks it is post-Hamilton and therefore of Late Devonian age. Thus the Upper Devonian of this paper extends from the base of the "Tully" (actually the top of the Hamilton) to the earliest Mississippian level. Fig. 1 shows the Mississippian outcrops in Pennsylvania and these in turn indicate by proximity the belts of the Upper Devonian. Note the Berwick anticline extending northeastward into a probable fault.

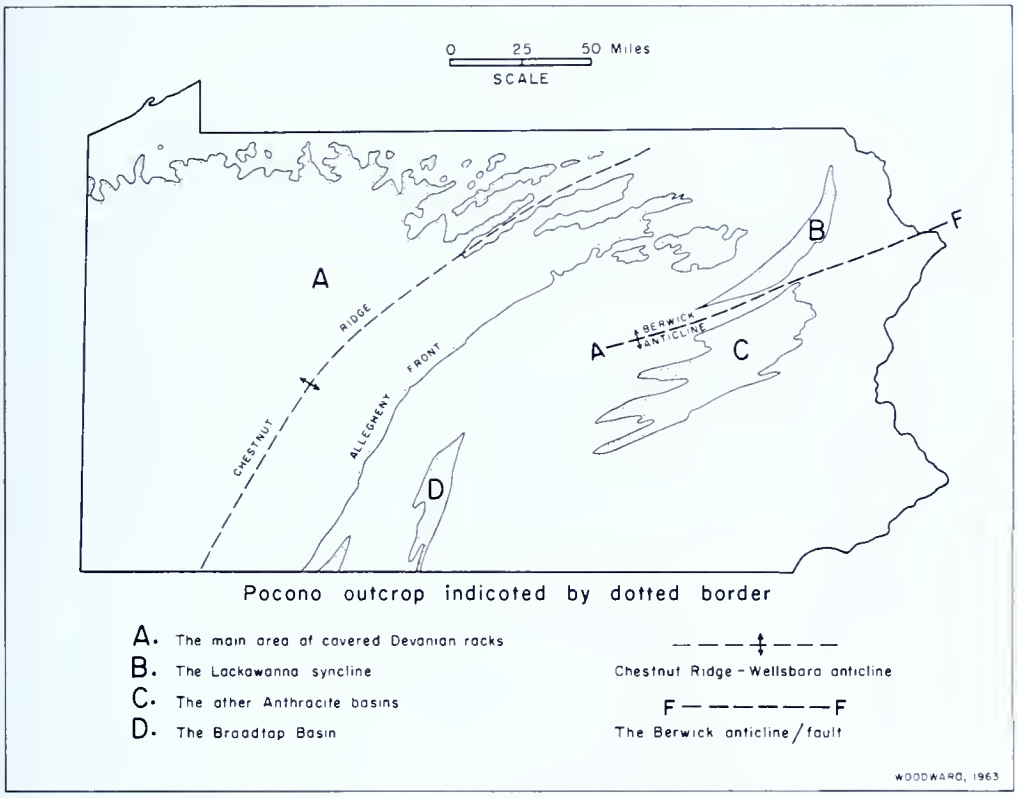

Figure 1. Sketch map of the Pocono outcrop in Pennsylvonio, from which the Upper Devonion outcrop con be locoted by proximity. The Berwick onticline is extended northeostword os o foult thot moy cross the Delowore just south of Shoholo-Borryville.

A complicated genus of stratigraphic problems hides in three words of the preceding paragraph, for the "Earliest Mississippian level" is genuinely difficult to establish. In a general way, the Cussewago, Bedford, and Berea units of the early Mississippian of eastern Ohio give way easterly to the Murrysville-Corry sandstones (Pepper et al, 1954), and these are replaced in southwestern New York by beds commonly called Knapp and Shenango, similarly assigned to the basal Mississippian. Still farther east, the same or a similar sandstone has been called "Pocono-Burgoon," terms themselves trailing complicating connotations. When the "Pocono" reaches central and eastern Pennsylvania, its stratigraphy becomes tangled by the addition of innumerable heavy conglomerates mostly of latest Devonian age. Finally, in the type Pocono Plateau, the Mississippian age of any sandstone is hard to establish, and consistency of designation either has been abandoned or was never attained.

The whole problem with both the late Devonian and early Mississippian, of course, is one of differentiating time-stratigraphic and rock-stratigraphic divisions, as excellently explained by Cooper (1934), Chadwick (1935–6), Caster (1934), Willard (1939), and others. As there has been

small paleontologic study of these rocks, the matter of bio-stratigraphic units has not yet been broached (exception, Greiner, 1957), and the current analysis treats only (a) rock bodies bounded by the same chronologic limits, and (b) lithic units—magna-facies, facies, etc.—having fairly constant physical features while they transgress time boundaries.

The following procedure was used in this analysis: A palinspastic map of Pennsylvania (Fig. 2) was constructed to eliminate, so far as possible, the effects of late Paleozoic folding. A section line (A–B) was drawn on this map so as to cross late Devonian isopachs roughly at right angles. Next, a series of regional zones was laid out to cross the section line at right angles; the zones were spaced to average about 30 miles in width. Within each zone, all available well-logs and sections were then aligned in geographic order from south to north, and a composite column was compiled for each zone. Finally, a synthetic cross-section was prepared along the entire section-line, using medial measurements for each of the several zones.

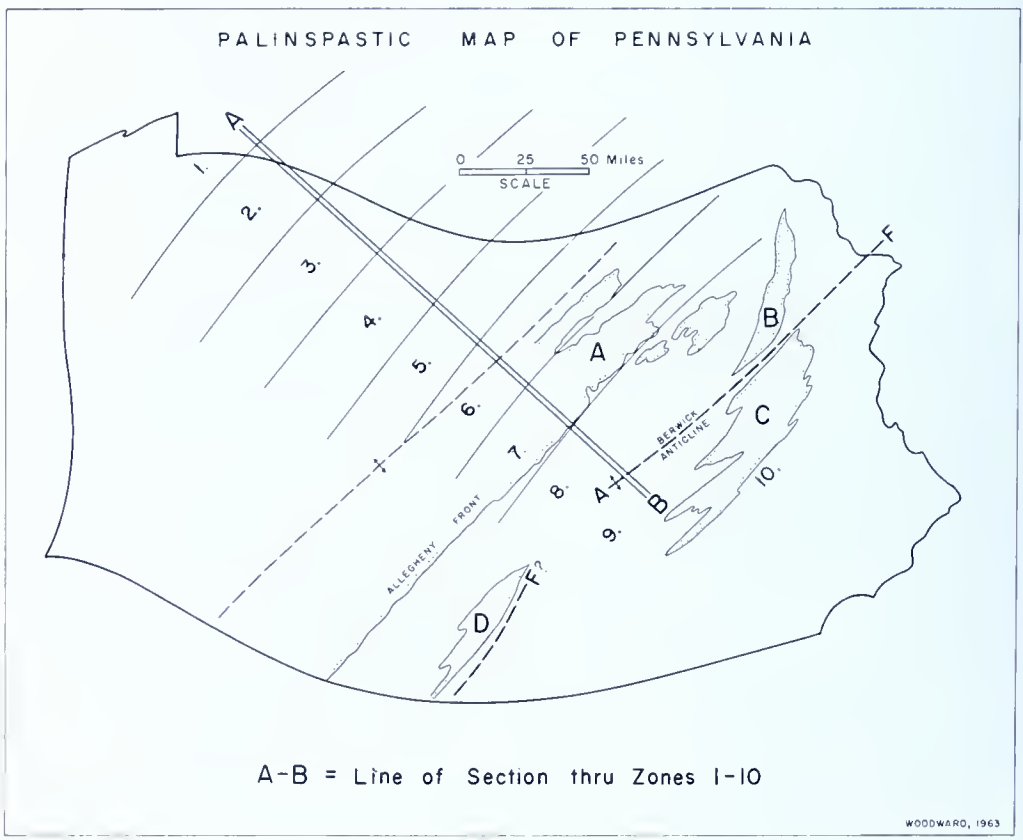

Figure 2. The duplicate af Fig. 1 drawn an o palinspastic base which eliminotes the results of late Paleazaic falding. The line A–B shaws the pasitian of the section on Figure 2, and the several zanes in which the stratigraphic data were assembled.

This detailed composite section was then extended eastward first to the complicated Anthracite and Pocono Plateau regions and then northeastward to the Catskill Mountains of southern New York. The original large-scaled section was condensed into its major elements and appears in reduced form as Figure 3 of the present report. The procedure eliminates by graphic reduction a large number of small but important stratigraphic matters—individual correlations, intergradations, intimate facies changes, etc.—but it provides some compensation by revealing the larger regional relations, and it is this larger pattern with which the remainder of this paper is concerned.

As interpreted from the original cross-section from which Figure 3 was reduced, all seven Upper Devonian stratigraphic divisions thicken toward the southeast, the rate of increase being different for the top and bottom halves of the upper Devonian. In the 165 miles from northwestern Pennsylvania to the Allegheny Front the four lower divisions of the Upper Devonian increase from 900 feet in Chautauqua County, New York, to 3,800 feet near Lockhaven, Pennsylvania, a more than four-fold increase at a rate of about 17½ feet per mile. The Canadaway increases from 1,100 to 1,850 feet in the same distance, its rate of increase being much less than for pre-Canadaway horizons. The total Conneaut and Conewango increase is even smaller, their combined thicknesses growing from 900 feet at the northwest to 1,300 feet at the southeast. It is rash to project these increases toward Delaware River and the Catskill Mountains but it seems likely that they would be found to continue at about the same rate were the section not worn off at its top by later erosion.

In a general way, chronologic and lithic divisions are reasonably consonant in the three westernmost zones, the Genesee, Sonyea and West Falls-Chemung divisions being predominantly shales at the bottom grading up into shales with sands toward the top. The Canadaway and Conneaut divisions are more arenaceous, while the Conewango contains the red Cattaragus shale overlain by the partly non-red Oswayo sandstone.

Halfway toward the Allegheny Front or near the 78th Meridian the true Oswayo sandstone pinches out of the section by erosion, as does the Cattaraugus shale a little farther east. Unconformably on top of these beds comes in a new, mainly arenaceous section starting with a basal sandstone that is commonly pebbly. This unconformity more or less levels off about 5,600 feet above the top of the Hamilton. The new group includes a lower member, perhaps 500 feet thick, that can be correlated with Willard's Cherry Ridge Formation (1939); a medial member about 150 feet thick which he calls the Elk Mountain Sandstone, and an upper unit (Mt. Pleasant) which thickens eastward and may reach 600 feet in the anthracite area. Each of these three formations contains a basal pebbly sandstone or conglomerate, and in eastern meridians there are medial conglomerates as well. In consequence, and because all three units strongly

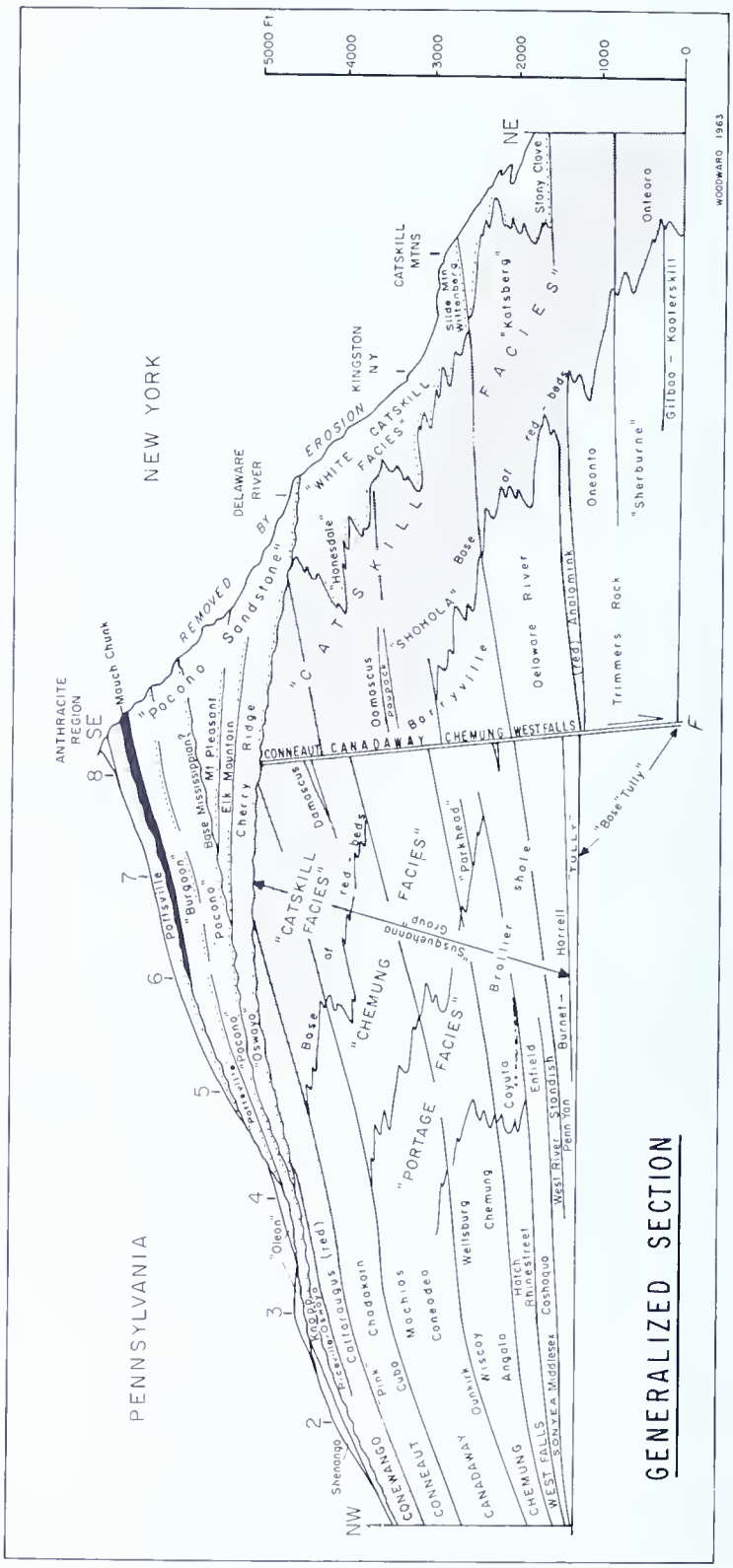

Figure 3. Highly generolized synthetic strotigrophic cross-section olong line A–B in Fig. 2, extended northeostword to the Cotskill Mountoins. Note the postuloted unconformity below the Cherry Ridge group, the eostern incurring "White Cotskill" focies, ond the postuloted pre-Cherry Ridge foult. Note olso the eostword oscending time-strotigrophic boundories, ond the descending lithic or rock-strotigrophic focies.

resemble the basal Mississippian in appearance, they all have been called "Pocono" at various locations, another error that confuses the literature of the region.

These three late Devonian formations intervene between the main body of the Upper Devonian and beds taken to represent the clastic Lower Mississippian. There is no group name for them yet, but one certainly seems to be in order, perhaps "Cherry Ridge"; probably they are of late Conewango age. The "true" Mississippian rises above them with an unconformable basal contact so that the total interval from the top of the Hamilton to the base of the Mississippian increases from about 3,000 feet in southwestern New York State to nearly 6,700 feet at Lockhaven, and doubtless would be close to 8,500 feet along the Delaware River if not curtailed by summit erosion.

These remarks so far relate primarily to what are regarded as time-stratigraphic units. Description of the lithic or rock-stratigraphic units is accomplished best if the section is considered in the opposite geographic direction.

The Upper Devonian of the Catskill region of New York—probably nowhere rising far above Sonyea ("Portage") limits—is dominated by the red "Catskill" mega-facies. Some of the highest summits, however, show remnants of white pebbly conglomerates (Slide Mountain; Whittenberg) that superficially resemble the Pocono-type conglomerates and constitute the so-called "White Catskill" facies which is the eastern lithic phase of the several mega-facies comprising the "Catskill delta." (Note that the underlying red facies in the Catskill region has descended into the Hamilton group of the Middle Devonian, well below the Tully horizon.)

These non-red sandstones and conglomerates of the white Catskill facies increase westward in abundance and thickness and they also rise in the stratigraphic column as one reaches Pennsylvania. In the region of the Pocono Plateau, east and southeast of the anthracite basins, they are prominent ridgemakers, one of them being called the Honesdale Sandstone by Willard (1939). This member helps to uphold the high berm and scarp of the Pocono Mountain resort region. This same "White Catskill" facies dominates but does not fill the lithology of beds designated as Cherry Ridge, Elk Mountain, and Mt. Pleasant Formations, so that the facies extends at least as far west as north central Pennsylvania. Failure to recognize this important member of the several late Devonian facies and—even more significant—its erroneous identification as true Pocono, have complicated field work and study in the region.

The red Catskill mega-facies rises from Hamilton and early "Portage" horizons in the Catskill region. It occupies the West Falls—Chemung horizon in the Delaware River region and the Canadaway-Conneaut horizons in the anthracite region. West of the Allegheny Front it has ascended above the base of the Canadaway, and ultimately it is nearly

restricted to the Cattaraugus member of the Conewango group. Mostly it ranges through about 2,000 feet of section at any given point, its boundaries transgressing upward across chronologic lines in a northwestward direction.

Note that a thin (0–350′) persistent sliver of the red Catskill facies insinuates itself between the Trimmers Rock and Delaware River Formations of Sonyea age, and can be traced for miles along the southeast Devonian outcrop in southern Monroe and Carbon Counties. This is the Analomink Formation of Willard (1939) and its horizon is about that of the base of the Cashaqua. It has commonly been mistaken by the field geologist for much younger elements of the Catskill facies and in consequence, various published cross-sections need revision.

A non-red sandstone-siltstone facies undergirds the red Catskill megafacies and can be called "Chemung facies." It is represented at the northeast by the Ashokan Member of the Hamilton Group, the Sherburne-Oneonta and Trimmers Rock-Delaware River units of the Sonyea Group, the Parkhead and "Chemung" Formations of the central Pennsylvania-Maryland outcrop, the Caneadea, Machias, and Northeast Formations of the Canadaway, and the Venango Group of the topmost Devonian in western Pennsylvania. It, too, is a west-rising facies and maintains a general thickness of 1,800 to 2,000 feet.

Underneath the "Chemung" facies is the so-called "Portage" facies, mainly an assemblage of shales and thin sandstone lentils of which the Braillier Shale in Pennsylvania, and the Ithaca-Enfield-Cayuta Shales of southern New York are typical. This facies is followed upward from below by a dark to black shale facies including the Burket-Harrell Shales, the Rhinestreet-Hatch sequence, and perhaps even the Dunkirk black Shale if the facies attains the level of the basal Canadaway.

As noted above and depicted in Figure 3, these several west-rising lithic facies intersect the east-rising time-stratigraphic units somewhere west of the 78th Meridian, and from that point westward, the two groups of units more or less coincide. The term "Susquehanna Group" (Miller and Conlin, 1959) has been lately (and perhaps unnecessarily) coined for the total of these several lithic facies between the top of the Tully and the base of the Mississippian in central Pennsylvania.

If these observations are correct, then the gross stratigraphic picture for the Upper Devonian of Pennsylvania can be summarized as follows:

1. A series of seven or eight time-stratigraphic units can be recognized at the northwest, and these thicken more or less regularly toward the east and southeast. Doubtless they can be subdivided into a number of significant formations many of which are fossiliferous.
2. Also in western Pennsylvania, these units are more or less coincident with several lithic or rock-stratigraphic facies, which are from top down, (a) a white or non-red sandstone facies becoming increasingly conglomeratic toward the east; (b) a red sandstone and shale ("Catskill") facies; (c) a non-red sandstone and siltstone facies ("Chemung");

(d) a shale and thin sandstone facies ("Portage"); and (e) a black-shale facies ("Naples-Genesee").

3. At about the 78th Meridian, while the time stratigraphic units continue to thicken southeastward so that true chronologic boundaries ascend in that direction, the several lithic facies or rock-stratigraphic units commence to descend in the time column. Traced into the Catskill region of New York, the white pebbly sandstone facies is at the base of the West Falls-Chemung horizon while the underlying red Catskill facies has dropped well into the Hamilton Formation of Middle Devonian age.
4. Also at about the same meridian the top of the main body of Upper Devonian rocks is truncated by an erosion surface lying about 5,600 feet above the top of the Hamilton. Unconformably above this surface comes in a group of three arenaceous formations which are cut off at the west by erosion but thicken and grow increasingly conglomeratic toward the east. This east-thickening wedge contains many members resembling the Pocono sandstone which complicate determination of the top of the Devonian east of the Allegheny Front.
5. Rocks probably equivalent to the Knapp conglomerate and believed to be of basal Mississippian age rise progressively above the thickening Upper Devonian pile, both truncating and covering the arenaceous group described above. At its easternmost exposure, the base of the Mississippian—perhaps the true Pocono sandstone—overlies 1,200 feet of very similar late Devonian sandstones to which many, in error, the term "Pocono" has been applied.

However much it is desirable, it is impossible in the space allotted for this discussion truly to document the above conclusions and the writer is genuinely unhappy in offering so bald a statement of opinion. His only consolation is that he has actually spent much time and effort on the problem and does have what he believes are supporting matters.

He should, remark, however, that some careful modern research both in the field and in the paleontologic laboratory should be devoted to the basal rock section regarded as "true Mississippian." Thus the "true Pocono" of both the Anthracite and Broad Top coal basins is still assigned to the Mississippian on faunal evidence that Chadwick, at least, thought could as easily be late Devonian as otherwise. The same kind of restudy should be made of isolated erosional remnants called "Knapp," Pocono," and "Olean," in New York and elsewhere, for these are not certainly placed in the column.

It may fairly be asked why an unconformity is postulated below the wedge of Late Devonian sandstones whose base is formed by the Cherry Ridge Formation; or why this contact could not be a simple facies change such as that effected by the base of the Catskill reds. The answer is that it is believed the entire geologic section below the Cherry Ridge Formation is cut by one or more major faults and that one must postulate a covering unconformity to explain this situation. The succeeding portion of the paper discusses possible interrelations of stratigraphy and structure.

STRUCTURAL SPECULATIONS

If a careful examination is made of sample logs for the wells recently drilled in northeastern Pennsylvania by Transcontinental Gas Pipe-line

Company, and if these data are matched with surface sections measured at Lockhaven, near Catawissa, in Schuylkill and Lehigh Gaps, along Brodhead Creek on the upper Delaware, etc., then it will be found that for about the lower 4,800 feet of the Upper Devonian, there is fairly close correlation from section to section. There are, of course, variations in lithology, thickness, and color, but one can follow various markers across northeastern Pennsylvania, e.g., a thin red seam below the base of the main red facies; a thin nearly black siltstone; the Analomink Member, the first change from non-silty to silty shales, etc.

This agreement suggests a regional uniformity of sedimentation, and it is confidently believed that definite stratigraphic units can be worked out in the subsurface; and where fossil and other internal evidence occur, that these will permit ready correlation with the better known surface sections west of the Allegheny Front. In a general way too, the rock succession described by Willard (1939) for northeastern Pennsylvania can be defended, although his thickness figures do not match actual well sections and some of his named units must be redefined.

Near the top or perhaps at the actual summit of this observed concordant section, there is a fairly persistent sandstone member 120 to 200 feet thick which can be identified on the outcrop as well as in well sections. It lies about 4,800 feet above the Hamilton and probably represents the so-called Paupack Sandstone of Willard's Shohola Group. It is everywhere overlain by a thin-bedded deep-red shale which corresponds to his Damascus Shale.

The first 3,000 feet of the Upper Devonian in this region contains at its base the Trimmers Rock Formation or its equivalent (1,350 feet), the medial red Analomink Formation (0–350′), and the Delaware River Flags (1,275 feet) at the top. The remainder of the section below the Paupack Sandstone contains the so-called Barryville Member of the Shohola Group which ranges up to 1,800 feet thick. Containing numerous elements of the red Catskill facies, this member is probably seated on top of the Sonyea Group, and it is believed to extend into early Canadaway horizons at its top.

In the same fashion although controlling data are far fewer and the element of personal opinion is more prominent, there is a similar regional concordance at the top of the Devonian. For example, the Pocono Sandstone appears to have once spread across eastern Pennsylvania in a thickness pattern that shows no points of unusual change. (See Fig. 5). As elsewhere noted, the basal Mississippian is believed to lie unconformably on a wedge of late Devonian clastic formations which in turn lie unconformably on the main body of the Upper Devonian. As nearly as can be determined from the present evidence, these relations hold fairly well for all northeastern Pennsylvania.

West of the Anthracite Basins, however, the distance between the top of the Paupack Sandstone up to the unconformable base of the Cherry Ridge clastics contains no more that 800 feet mainly of red units of the Catskill facies. Here then what Willard calls the Damascus Shale (Montrose Shale of White, 1881) essentially extends from the Paupack Sandstone to the basal Cherry Ridge. East of the Anthracite Basins, the interval from the basal Cherry Ridge down to the Paupack is nearly 2,000 feet greater and this difference seems to be constant and not regionally variable.

Two distinct facies appear in this thicker eastern section. Toward the southwest the added section contains mainly red Catskill facies, and the Damascus red Shale passes upward into more than 2,000 feet of other Catskill types. Toward the east, however, the added section contains "White Catskill" facies as in Schuylkill and Lehigh Gaps where there are 2,000 feet of green (and some red) sandstones that have no counterparts west of the coal basins.

On this account, as indicated in Figure 3, it is believed that there is a concealed major fault or displacement which involves the entire rock section below the Cherry Ridge Group but does not affect the latter or the overlying Pocono Sandstone. If this interpretation is correct, then the basal contact of the Cherry Ridge Group must be uncomformable as previously described. The development of the fault must be assigned to a Conneaut or early Conewango time, and it is suggested that it is a function of what is commonly called the "Acadian"effort.

On the basis of what is patently fragmentary evidence, the fault is presumed to be one in which the eastern or southeastern side is down-dropped with respect to the western or northwestern side; but it is not known whether the displacement is a "gravity-type" fault or a wrench fault involving lateral dislocation.

If such a fault in fact exists, then various stratigraphic relations fall into better arrangement than the writer has been able to compose them without faulting; yet the break has been postulated solely on circumstantial evidence and should have better support than this. For example, there should be some field indications of dislocation, and certainly its presence should be detected on accurate isopachous maps of the formations disturbed. Furthermore a break of this magnitude must extend below the Devonian and there should be confirming evidence in earlier Paleozoic systems if it is a genuine and not an imaginary structure. Clearly such confirmation requires a great deal of experimental reconstruction of both older ideas and present data. Very little of this has been done as yet mostly because so little critical information is yet available.

Nevertheless, some supporting data have turned up, but they lie within a frame of reference which the writer has never seen explored or even described. Hence before they can be presented, a somewhat novel setting

must first be outlined and an answer found to the general question: What happens to a pre-folding Appalachian fault when the sediments dislocated by it are later crinkled into great folds?

One may start with the essentially recent conviction (Rodgers 1949, 1953; King, 1950) that most Appalachian folding is primarily a shallow (or "thin-skinned") feature wherein the sedimentary carpet alone has been deformed or folded while the underlying basement has not been correspondingly displaced and certainly was not involved in the degree of deformation permitted by the weaker overlying sediments.

If, now, there was a more or less vertical displacement that antedated the main epoch of folding and if this fault affected both the sedimentary carpet and the basement beneath it, then it seems likely in the event of any later folding that the actual break in the sediments will be shifted from its former position above the corresponding rift in the basement.

Hence, for its proper interpretation, any such folded fault-line should be studied on a palinspastic map (Woodward and Dennison, 1963) that eliminates all effects of post-faulting folding. When so plotted, the displacement in the sedimentary carpet should then be restored to (or near) its original site above the displacement in the basement. Doubtless, many traces of the break in the sediments will have become so blurred by shearing during folding that they could be overlooked in a casual field survey; and certainly that they will now occupy a position apparently unrelated to their roots in the undisturbed or less displaced floor beneath them.

It is this approach which the writer finds uncharted by previous use or description, requiring the simultaneous utilization of data plotted on regular coordinates and also on their palinspastic equivalents. For the present project, using transparent acetate with a matte surface, he developed two geologic maps of Pennsylvania on the same scale of 1:1,000,000, one in its normal or present arrangement, the other on a palinspastic base. By alternately superimposing the two maps and transferring data from one to the other, he found himself better able to appreciate the time dimension than by the use of either map alone.

In consequence, for such a pre-folding fault as has been postulated below the latest Devonian and Pocono formations, there may be *three* geographic sites to examine on a normal or present day geologic map of the region: (1) the present field position of the break in the sediments, now dislodged by folding; (2) the probable pre-folding position of this sedimentary dislocation; and (3) the probable original position of the rift in the basement, which may coincide with site 2 but will surely not correspond with site 1.

In theory, provided the palinspastic map is correctly constructed, any two of these geographic lines can be calculated from the known third. The complication—which is a very genuine one in the Upper Devonian

problem under discussion—is to discover and identify any one of the three, in other words, to find any handle at all with which to grasp the problem.

If it can be found in the field, site 1 (the present location of the sedimentary break) can be adjusted to its former position (site 2) by replotting on the palinspastic base and then tracing this new location back to the regular geologic map. If examination of that line in the field or on the geologic map shows other evidences of faulting, then is is likely that this also is site 3. It is possible, of course, that these evidences are misleading and should themselves be considered in their original prefolding position; hence one should replot site 2 on the palinspastic map using whatever coordinates are indicated on the regular map. Finally this new line should be traced back from the palinspastic base to the original geologic map.

For any Appalachian-type folded region, this procedure will produce three routes on a geologic map, and one or more of them—or some intermediate line—may have genuine validity. In the specific Upper Devonian problem at hand, at least one major pre-folding fault has been postulated to cut Devonian and earlier sediments below the latest clastic sediments. Where are the effects of this fault located today and where was the original site of the faulting?

One possible answer is already at hand. From independent lines of evidence, Woodward (1963) and Drake (1963) separately have suggested that there is a major right-lateral shear or wrench fault that extends west-east more or less along Longitude N. 40° from the subsea Kelvin Seamount group (about 400 miles off the Jersey shore) at least to south-central Pennsylvania. (See also Norton, 1960, and Gilliland, 1962.) The movement along this major displacement may amount to 85 miles, the block south of the fault-line having probably been displaced that distance with respect to the block north of the fault. As the rift is believed to pass near Cornwall, Lebanon County, Pennsylvania, the authors have tentatively called it the Cornwall-Kelvin displacement (Woodward and Drake, 1963). They have so far completed only preliminary research on the problem but the evidence for a genuine dislocation is accumulating.

Mainly on Woodward's conclusion, a pre-Pocono and post-Hamilton age has been adduced for the Cornwall displacement, this date having been suggested by a comparison of isopach maps for the Upper Devonian (Fig. 4) and the early Mississippian (Fig. 5). Initial comparison was made between the isopach map of Jones and Cate (1957) for the Upper Devonian and an analogous map by Walker (1962) for the early Mississippian. Both maps have now been redrawn, and while the revisions are quite different from the originals, the same date for the fault is again reached. Woodward has also traced what he thinks is the western extension of the Cornwall displacement, and believes that it trends southwestward across central-western Maryland into West Virginia. Possibly it can be con-

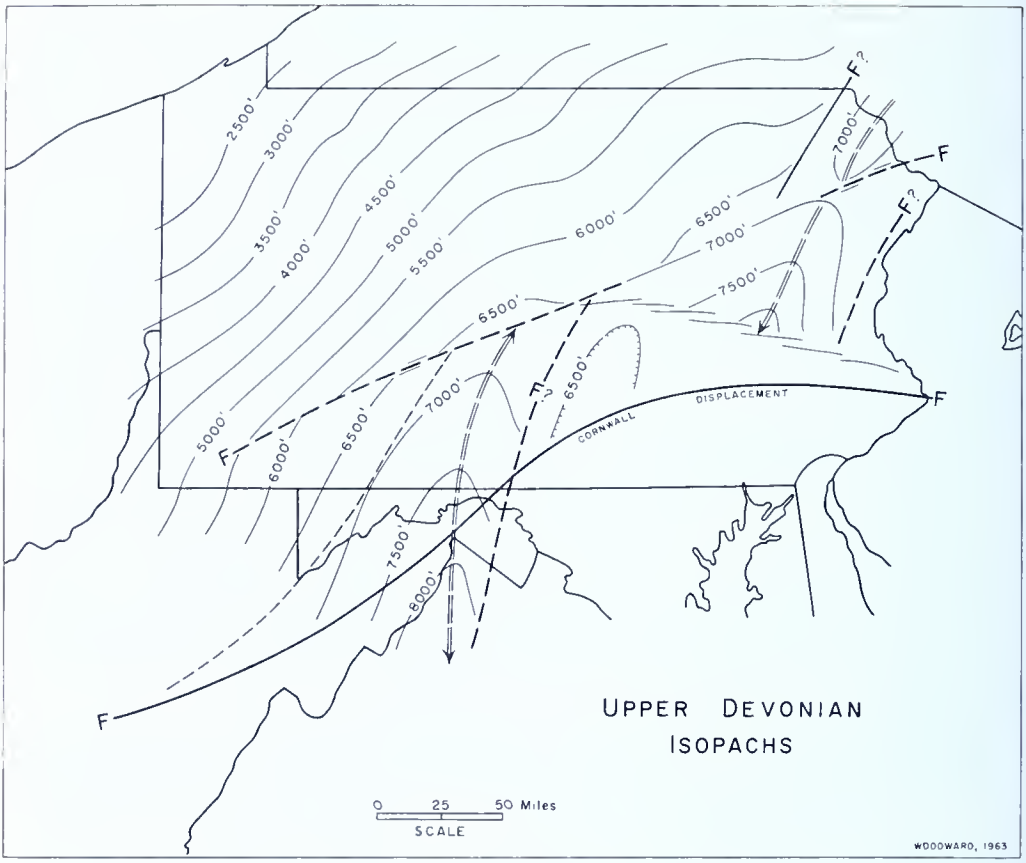

Figure 4. Possible Upper Devonian thicknesses as shown by 500' isopachs.

nected with the steep declivity which he has earlier described (1961) in eastern Kentucky. (See also Watkins, 1963.)

Fig. 6 shows the postulated position of the Cornwall fault (site 2 as described above); the probable position of sediments once sited above the faultline (site 1); and the prefolding position (site 3) of elements now situated on site 2 if they, too, were dislodged by folding.

Three other sketch maps show the possible historical development of the Cornwall displacement. Fig. 7 shows the situation before faulting, with the crystalline uplands of New Jersey (including the medial Green Pond syncline) lying east of the main Devonian sedimentary sag or basin. Fig. 8 suggests the direction and movement of the fault producing offsets in the regional features. Fig. 9 shows the assumed situation after arcuate folding has displaced the sediments once situated above the rift when it first developed.

The Cornwall fault is doubtless related to the arcuate folds directly opposite one component of its compressive movement, but these relations have not yet been worked out in detail. Nevertheless there is a distinct possibility that the fault postulated in the Devonian sediments beneath

the "White Catskill" facies is related to the epoch of Cornwall faulting. If it is not the main displacement, it may be an accessory feature. This idea is still speculative and untested, and it is hoped that some information may come out of the present symposium which will bear on the matter.

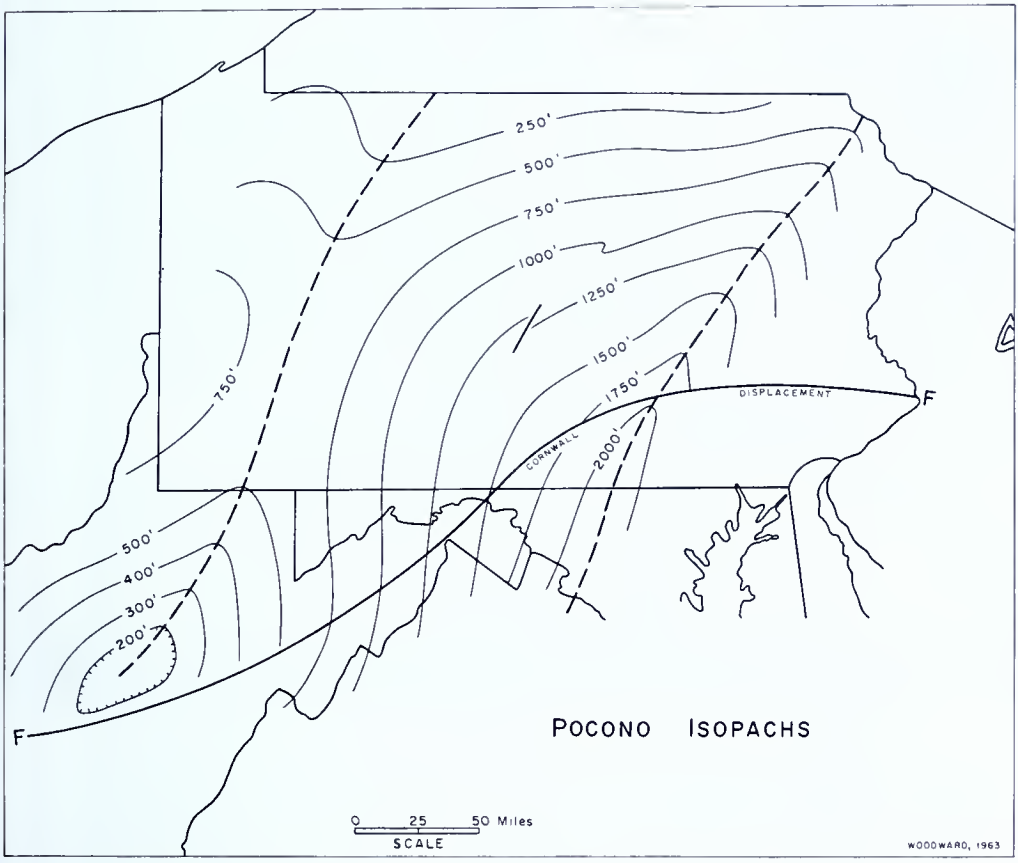

Figure 5. Possible Pocono thicknesses os interpreted in this poper, shown by 250' isopochs. Compore with onologous mop by Wolker (1962).

There is a little field evidence that another unmapped fault does indeed cross eastern Pennsylvania. This structure, it is believed, is related to or follows the Berwick anticline which forms the structural separation between the northern Anthracite Basin (the Lackawanna syncline) and the two southern basins. The fault can be traced eastward from the anthracite area as a line of sharp flexures in the exposed Upper Devonian rocks and is believed to cross the Delaware River just south of Shohola-Barryville. It is thought that it may cross Shawangunk Mountain between Manakating and Summitville. Probably this was the fault that was cut in the Good well recently drilled in central Luzerne County. (See Figs. 1, 2, and 4).

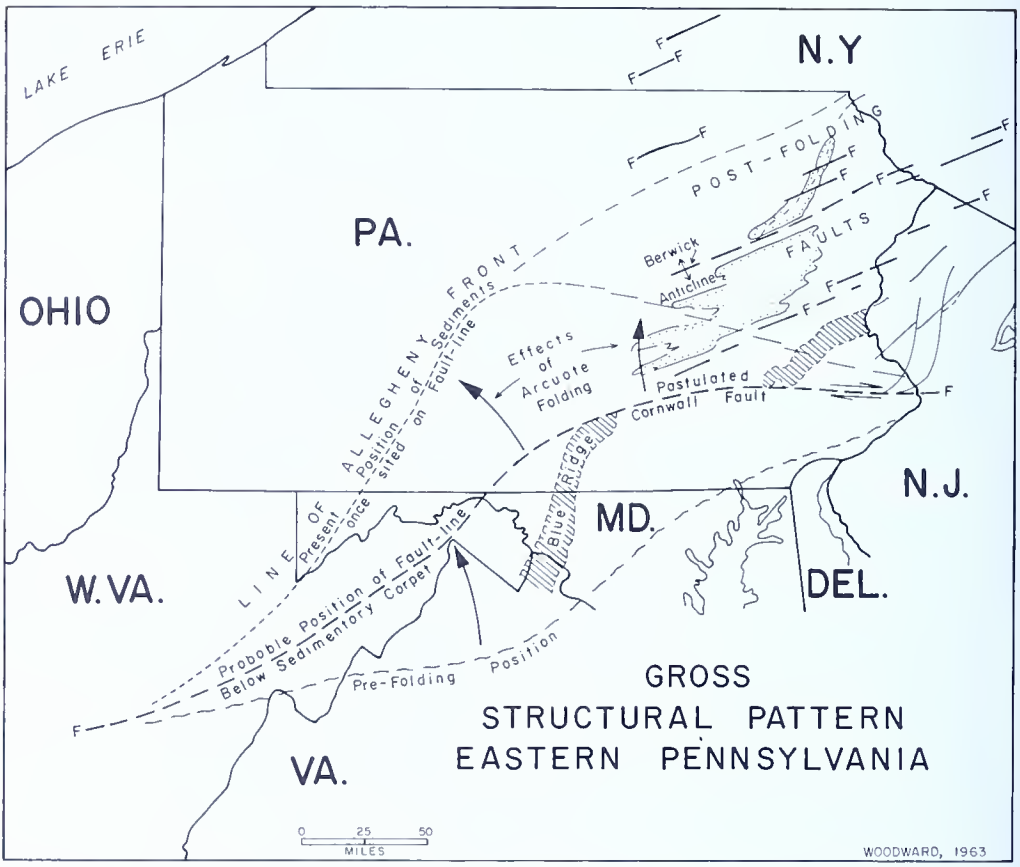

Figure 6. Grass structural pattern far eastern Pennsylvania shawing the Carnwall displacement. Nate an this map that the Berwick anticline/fault is matched by faults that may be post-falding; hence it cauld be af this age.

Study of the excellent isopach maps of Devonian formations by Jones and Cate (1957) as well as analysis of the writer's independent maps suggests that there are geniuine stratigraphic irregularities along this line, and perhaps these can be traced in the bedrock as far as Westmoreland and Fayette Counties in southwestern Pennsylvania. No similar indications seem to involve the Pocono Sandstone, although that formation is indeed absent along the fault-line south of the Lackawanna syncline. A straight-line westward projection of the strike of the Berwick anticline would take the fault out of the arcuate folds near Holidaysburg, possibly into (under?) the Pocono escarpment near the tri-county boundary of Somerset, Cambria, and Bedford Counties.

The course which has just been laid out for this possible displacement is essentially a straight-line route, yet the fault is thought to be pre-Pocono. As it would be odd if the arcuate folds of central Pennsylvania could dislodge an older route into what is now a straight line, some part of the above argument does not hold water; either the assigned age of the

fault (see Fig. 6), or part of its described route may be erroneous. If its present position is calculated on the palinspastic base and then traced back to the modern geologic map, the eastern part of the fault-line is seen to assume a more southerly trace and to strike underneath the Triassic cover in southeastern Pennsylvania, perhaps becoming involved with the Cornwall structures.

One more suggestion will be made, perhaps of still another displacement. When the original positions of the anthracite basins are located on the palinspastic base, it is plain that a line along the west margin of the Lackawanna syncline if projected south-southwest would more or less coincide with the east flank of the north end of the Blue Ridge if similarly restored on the map. This is a line that, very much later, was followed by Triassic or post-Triassic faulting, and there is some reason to believe that most such younger dislocations are posthumous, i.e., related to an earlier fault or fault-line.

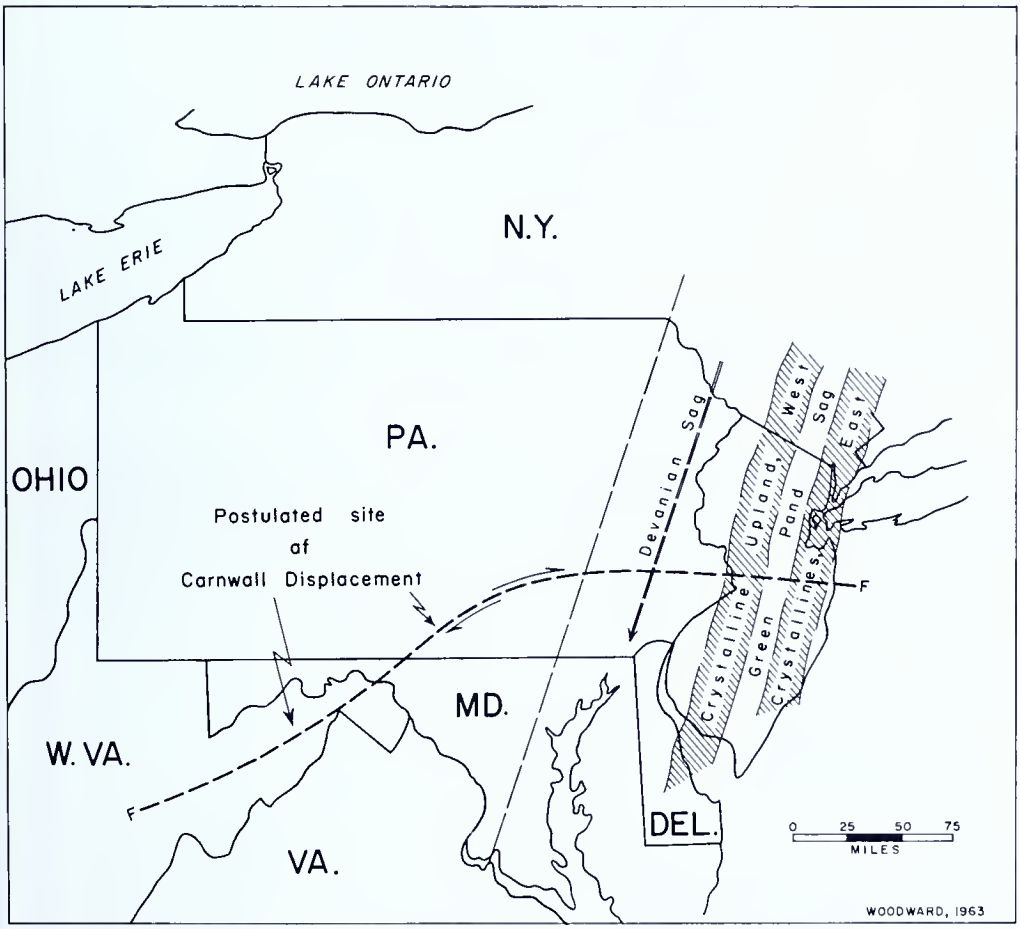

Figure 7. Generolized restorotion of elements prior to the Cornwall foulting. Time, post-Homilton ond pre-Pocono.

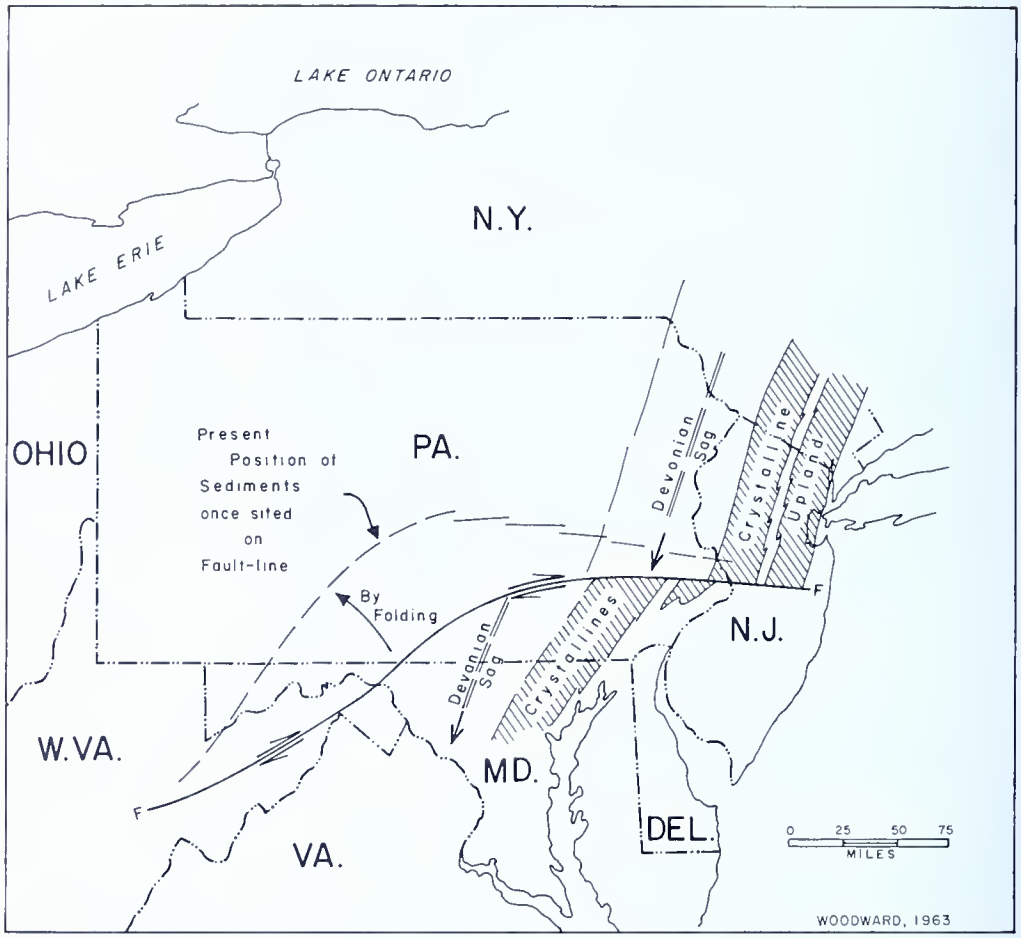

Figure 8. Generalized restaratian af elements as adjusted ar disladged by the Carnwall displacement. Time, probobly late Conewongo.

It is thus suggested that there may be a sub-Pocono fault or displacement underneath the Lackawanna syncline or along its western margin, and if so then this structure may slightly precede the later movement along the Cornwall displacement, for the latter is believed to cut across any early dislocation sited along the Lackawanna structure. By implication, a similar longitudinal dislocation may underlie the Pocono in the Broadtop synclinal basin.

It is high time to terminate this excursion into untested and perhaps unsupportable speculations. Nevertheless, it is felt that a new method of stratigraphic and structural approach has been described which should be genuinely useful for structures that have later been displaced by pattern deformation. Stated in its simplest terms, the procedure is to construct for the area in question an accurate palinspastic map on the same scale as the geologic map of the locality. Ideally, both should be transparent. A possible structural line is observed on the geologic map and its

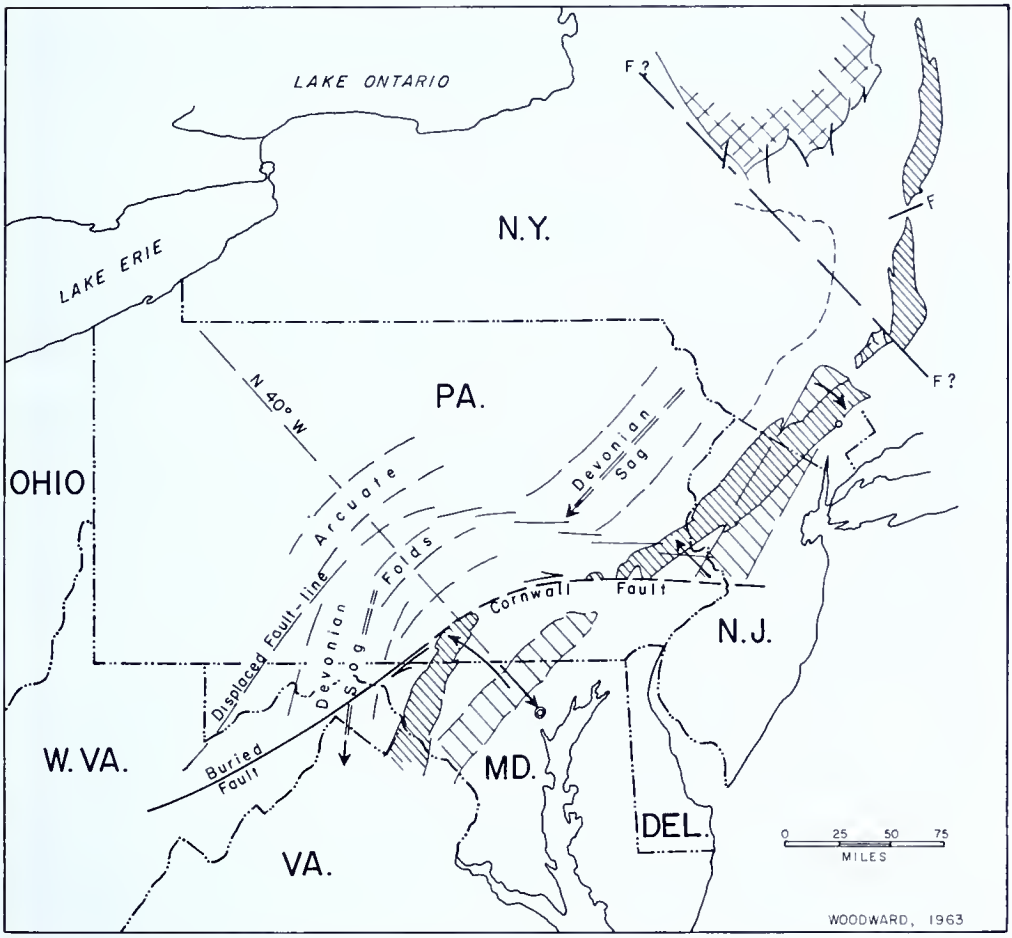

Figure 9. Generalized restoration of elements following the late Paleozoic folding which displaced locotions shown in Fig. 8. Time, soy post-Permion.

pre-folding position is then drawn by hand on the palinspastic base. This line is now traced back to the original geologic map where it will take a different course, and the problem is to see if this new course also shows evidences of some related structural control. The possible time-separated identities of these two routes opens up, it seems to this writer, a field that has been entirely neglected in regional geologic studies.

Judged by even so generous limits as those of William Morris Davis' "outrageous hypotheses," the suggestions made in this section fall short of qualifying as valid scientific contributions. Nevertheless there are several matters even on so small recommendation that should be given more thought. Two can be phrased in question form:

1. Is it possible that there are one or more major faults or displacements in eastern Pennsylvania that have been entirely overlooked because they do not involve the Carboniferous or highest Devonian, and if so, could they be situated as discussed above?
2. The concept that the sedimentary carpet and its floor have been differently affected by Ridge and Valley folding is new. If this is a genuine possibility, is it not possible that

the effects of faulting in the sedimentary overburden can now be differently sited than the traces of the same fault in the less deformed basement, and would not a palinspastic map, if correctly delineated, help reconcile these contrasting positions? If the answer is affirmative, is not this a valid new angle of approach to the stratigraphy and structure of eastern Pennsylvania?

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